# Can Open Science Change the World?

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*Computer hosts a virtual roundtable with six experts to discuss the potential and effects of open science.*

Open science is changing the way we approach science. Will this have any impact? Can it help us make global responses to global crises?

Open science involves efforts that endeavor to make the scientific process and research outputs more widely accessible to all. There is no formal definition of open science. However, a recent "Dear Colleague Letter" from the U.S. National Science Foundation captures much of what could be considered a definition.[1] Another frequently cited definition is provided by the FOSTER portal.[2] This might include scientific papers, data, software applications, and, potentially, scientific infrastructure. Open science is being promoted not only by funding agencies but also by communities of researchers, and there are many international movements that advocate open science practices. There are claims that by this opening up science to the world, there will be widespread benefits.[3] This may be vital when attempting to form a global response to global issues, such as climate change, pandemics, Sustainable Development Goals, and so on.

However, open science comes with costs—making scientific artifacts openly available requires extra effort, support, or reallocation of resources. Along with this comes ethical issues—is it right to share everything without protection? How do scientists trust that their works are used ethically and not misused or exploited? To explore the impact of open science, we posed six questions to a panel of six experts: Margaret Loper (Georgia Tech Research Institute), Adelinde Uhrmacher (University of Rostock), Roberto Barbera (Catania University), Paolo Budroni (Technical University of Wien), Kathleen Shearer (Confederation of Open Access Repositories), and Omo Oaiya (West and Central African Research and Education Network). (See "Roundtable Panelists" for more information about the panel.) Their responses and insights are presented here.

***COMPUTER*:** What is open science?

**MARGARET LOPER:** I came across a book chapter published in 2014 that I think puts a great framework around it.[4] It talks about five schools of thought related to open science. The measurement school is aligned with impact factor, peer review, and citations of publications. It's geared around scientific contributions and their impact and how you measure that. The democratic school is the idea that the access to knowledge is unequally distributed. So, how

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## ROUNDTABLE PANELISTS

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**Omo Oaiya** is the chief strategy officer of the West and Central Research and Education Network (WACREN). He was the pioneer CTO of the regional WACREN and continues to work with development partners and sister regional networks to develop high-capacity network infrastructure for research and education. Oaiya received a bachelor of pharmacy degree. Contact him at omo.oaiya@wacren.net.

**Adelinde Uhrmacher** is a professor at the University of Rostock and former editor-in-chief of *ACM Transactions on Modeling and Computer Simulation*. Uhrmacher received a Ph.D. degree. Contact her at lin@informatik.uni-rostock.de.


do you make that knowledge more freely available? It talks about things like open access, intellectual property rights, open data, open code, and so on.

The public school is the idea that science needs to be accessible to everybody. So, if government is funding people to do research, that research actually belongs to the people who funded it, not just to the person who conducted it. The kinds of topics in this area include citizen science, science blogging, and so on. The pragmatic school talks about how scientists work together, more openly and more collaboratively. How do you create those motivations, environments, and relationships to collaborate? Areas within this include the wisdom of the crowd, network effects, and, again, open data and open code.

The last one is the infrastructure school. These are the platforms and frameworks that enable all types of collaborations and open science to occur. They talk about things like open tools and collaboration platforms—interfaces that allow the openness to happen.

**ROBERTO BARBERA:** People are starting to separate science and open science. I think that this is completely misleading. Open science is good science, science that scientists (should) normally pursue. In the last 20 years or so, more scientists are obliged by research evaluations and career systems to go for publications and to compete. Science has become different from the original meaning of collaborating to solve problems and understanding how nature works and can be explained.

Open science is what science should be. We have been talking about open science for seven or eight years already. I think that, in a few years from now, we should just start talking about science and carry on scientific endeavors and different investigations under the open science principles. So open science is, in a way, what our science should be. We need to let researchers follow open science without losing opportunities to compete and progress in their careers while they share data, publications, and their other research outputs.

**PAOLO BUDRONI:** When we modern people talk about open science, to say that something is open, it means that other things are not open. So, open science is what has happened for centuries and centuries and is nothing new. The knowledge of how to cultivate grapes and produce wine, for example, is a model our culture has had for centuries—the ways to produce wine and oil and salt were things that were shared and were open.

If we take a look at the medicine used in Egypt, Anatolia, Greece, and Rome, for example, these cultures combined knowledge and various techniques using different tools, methodologies, and ingredients. Like Galileo did later, for example, they practiced their science recorded from discoveries in the ancient world, and this knowledge was spread all over the world. Having permanent access to this knowledge—this is the characteristic of open science. If we think of today's situations, for example, COVID-19 data, humanity needs access to these data, not only because we follow some utilitarian logic but because we should also follow sets of ethical values. We all need these—a common knowledge and a common sense of having knowledge shared.

**KATHLEEN SHEARER:** I guess, at its essence, open science is about sharing and collaboration—sharing all valuable types of research output, making the assessment of research more open, open infrastructures and tools, and working in a collaborative way. I agree with Roberto in the sense that it kind of represents a change in the mindset of where we have gone in the past few years, a kind of paradigm shift away from science that has been incentivized through competition between and across scientists and scientific teams.

It's kind of a recognition that, maybe, the most effective way to advance science and research is actually to do it collectively by working together and sharing widely research outcomes across communities. And I think this competition has been exacerbated by the commercial industry that's been built on top of shared publication research outputs. It's a move back to where science was initially many, many years ago, as Roberto and Paolo said, that science was really built on scientific collaboration, not competition.

**OMO OAIYA:** This new movement is attracting global attention. And from where we sit in national research education networks, it seeks to make scientific processes more transparent and accessible, and it involves making everything—the research materials, the data, lab procedures, and the eventual research papers—freely available online. I suppose that sort of lends to the collaboration that previous speakers have mentioned. This creates opportunities for scientists to evaluate and analyze what's there and to speed up, which is particularly important from our context in Africa—speeding up scientific discoveries minimizes the redundancy in experiments and provides a mechanism for innovation and economic growth.

**ADELINDE UHRMACHER:** From a modeling and simulation (M&S) point of view, beyond open access publications, the central question to further open science in this area is how the main processes and products of M&S can be made more transparent and easier to access. M&S research includes methodological developments as well as simulation studies in diverse application fields. Thus, answers to this question need to take the characteristics of the diverse products and processes into account. To simply publish simulation models or data is not sufficient; the annotation with suitable meta-information is the crucial step for not only accessing but assessing (and, thus, reusing) the products of M&S. (M&S has several documentation standards to support reuse that might inform other fields—see "Additional Reading.")

***COMPUTER*:** How does one become an open scientist?

**BARBERA:** Scientists try to follow and apply an atomistic procedure that, for centuries, we have called the *scientific method*. Iteratively, we observe natural phenomena, we run experiments, we make conjectures and hypotheses, we collect data, we analyze, and we compare experiments with theories. Open science and open science paradigms inform scientists how to share their research outputs and to actively collaborate, for example, the FAIR principles. (FAIR is a set of guiding principles to make data findable, accessible, interoperable, and reusable; it was first published by Wilkinson et al.[5]) The problem is that to have open scientists, the environments where scientists carry out their work should let them be open scientists.

> In education and training, there is a knowledge gap between open scientists and scientists in terms of the tools needed for open science.

In education and training, there is a knowledge gap between open scientists and scientists in terms of the tools needed for open science. Also, in many countries, a mechanism is missing to incentivize researchers to be open scientists. Careers are based on very competitive science, and (arguably) people are forced to publish papers without paying so much attention to quality. There is also a problem in the process of research evaluations. All countries carry on periodic research evaluations and assessments. In many cases, this is done with quantitative parameters relating to publications and does not really account for how science can be evaluated.

To be an open scientist, scientists need to close the gap and be acquainted with new tools to share their research. Governments and funding agencies should try to make an assessment on how science can really be evaluated. Without a change in this, it will be difficult to have open scientists, as they may be considered (or, worse, they may consider themselves) second-class scientists. This must be avoided at all costs.

**BUDRONI:** I'd like to be provocative. To be an open scientist depends on the

## ADDITIONAL READING

The following are examples of modeling and simulation metainformation documentation.


- T. Monks, C. S. M. Currie, B. S. Onggo, S. Robinson, M. Kunc, S. J. E. Taylor, et al., "Strengthening the reporting of empirical simulation studies: Introducing the STRESS guidelines," *J. Simulation*, vol. 13, no. 1, pp. 55–67, 2019. doi: 10.1080/17477778.2018.1442155.
- H. Rahmandad and J. D. Sterman, "Reporting guidelines for simulation-based research in social sciences," *Syst. Dynam. Rev.*, vol. 28, no. 4, pp. 396–411, 2012. doi: 10.1002/sdr.1481.
- V. Grimm, U. Berger, D. L. DeAngelis, J. G. Polhill, J. Giske, and S. F. Railsback, "The ODD protocol: A review and first update," *Ecol. Modell.*, vol. 221, no. 23, pp. 2760–2768, 2010. doi: 10.1016/j.ecolmodel.2010.08.019.
- D. Husereau, M. Drummond, S. Petrou, C. Carswell, D. Moher, D. Greenberg, et al., "Consolidated health economic evaluation reporting standards (CHEERS) statement," *BMJ*, vol. 346, p. f1049, 2013. doi: 10.1136/bmj.f1049.
- D. Waltemath, R. Adams, D. A. Beard, F. T. Bergmann, U. S. Bhalla, R. Britten, and N. Le Novère, "Minimum information about a simulation experiment (MIASE)," *PLoS Comput. Biol.*, vol. 7, no. 4, p. e1001122, 2011. doi: 10.1371/journal.pcbi.1001122.


mindset. Entering a building of the university where I studied, a university with eight Nobel prizes, there was an inscription: "Science and its teaching are free." This comes from the Austrian Constitution, Article 17a, which says artistic creation and the teaching of art are free.

So, what does it mean? This is a mindset thing. Try to understand how society should work. Many European constitutional systems expressly recognize the freedom of research and teaching in arts and science. They all say, in art and science, research and teaching are free, or freedom of scientific research is an endeavor that shall be guaranteed. There are also three levels of protection given to the freedom of science that can be recognized. The first is scientific freedom (and thought and expression) with the same protection that is given to all fundamental rights. The second is specific and complete constitutional recognition for such a fundamental freedom. Finally, the state is engaged in promoting scientific research.

So, open science is a mindset, and open scientists are a product of this. Open science means that we need people who are able to think.

**SHEARER:** To return to a kind of pragmatic level, open science means the willingness to collaborate, but it also requires researchers to learn some new practices. There have been a couple of surveys over the past few years of researchers, and one of the major barriers they found for researchers, in terms of data sharing and practicing open science, is that they just simply didn't know what to do to share their data in an appropriate manner and what the best practices are. So, I think there's a real need, as Roberto said, for training and education with the research community in terms of what those best practices are. We need to move away from this kind of ad hoc sharing that we are doing at the moment to develop and adopt standards and ensure that scientists and researchers know what is required and how they can become more open in their scientific practices.

**OAIYA:** My understanding and the approach that we are taking is more on the pragmatic side that Kathleen mentioned. When we want to think about open scientists, especially in an African context, we're thinking of researchers who publish openly in open access repositories employing reusability practices. It's looking at how their data and works use digital object identifiers (DOIs) [a DOI is a persistent identifier, certified by the International Organization for Standardization, that is used to identify objects uniquely, typically resolved to access the digital object via metadata bound to the object (such as a URL)], research identifiers [a similar concept to DOIs that are persistent identifiers for researchers (for example, ORCIDs)], and so on, and how these can be linked together to improve their visibility. Also, it's how they can use the right licenses for their outputs to share and make collaboration a whole lot easier. (More information about how licenses can be used to define sharing rules can be found at https://www.creativecommons.org.) That's typically not what we think when we think about open science. It's what we're trying to set up to support and advocate for open science.

**LOPER:** Start with small steps toward open science. For example, are there data I can share that may be beneficial to someone? If so, where should I put them? I agree with Kathleen in terms of having more training and best practices, adopting standards. When I think about the type of organization that I work for, I think we have gone down this path. Of course, it's just in small areas, like collaborating by sharing software and data. A lot of it has to do with building trust with the people whom you're working with and whom you're going to collaborate with. This involves building trust that you're both in this for the greater benefit of what you're trying to accomplish and not the personal benefit of what you will get. For example, will I get more visibility, more notoriety, or more money? These might be natural reasons for people to think about not sharing because they want to focus on their own advancement.

The mindset should be about the greater scientific impact and what you can do together collectively. Also, how does it impact practice? The coronavirus is a perfect example. Where the work you're doing involves the world coming together to look at epidemiology, modeling, and so on, it's about how to band together. It's not about any one person's notoriety, it's about trusting those that you're working with and having organizational policies in place that enable you to contribute to these open science projects that will have a greater impact on the world and not just on your career or your organization.

**UHRMACHER:** One possibility to become an open scientist is possibly as a response to frustration. Frustration at being unable to replicate a simulation study of another group or failing to understand the theory behind a simulator someone else designed. Another possibility is by an intrinsic desire to think things through. Having a product is one thing, but to make it accessible requires looking at it from a different angle. You must figure out how to describe it, how to facilitate deployment for someone who has not worked with the software. Although this requires some extra work, with the right mindset, it can be an amazingly rewarding task.

***COMPUTER*:** What services and infrastructure are needed for open science?

**BARBERA:** Research data are big. You cannot expect human beings to search and find what they're looking for, especially if they're looking for something that is completely hidden in correlations among different kinds of research outputs. Research outputs, in general, should be easily accessible by computer programs, and humans should be able to search easily in a human language way. FAIR data and infrastructure should be able to support both.

There is also the need for trust. I could use a search tool like Google. If I asked myself, "What are the most effective drugs against COVID-19?" I could find the thousands or even more than thousands of results. And, maybe, in some cases, they are fake. Or I might say, "How should I manage personal protection equipment?" Again, a huge number of results, but no trusted results. Reusability and reproducibility play a role in trust. Should reusability and reproducibility be part of the data itself, and how should a FAIR infrastructure facilitate this?

Of course, this doesn't come for free. There are costs for infrastructure and also for the training and education of scientists, programmers, engineers, and computer scientists to create this intersection.

There is the saying: "If you think education is expensive, try ignorance." The same applies to data. If you think that open data are useless or expensive, try closed data. The European Commission coordinated a study to evaluate the cost of not having FAIR data,[6] and the estimated direct costs are on the order of 10 billion € per year, increasing to 16 billion € per year if indirect costs are also included. The cost of open science infrastructure is nonnegligible, but the cost of not having it is even more. Government and international organizations need to come together and see how this could be effectively and sustainably funded.

Open science is a mindset, and open scientists are a product of this. Open science means that we need people who are able to think.

**BUDRONI:** Well, Roberto said the most important and crucial things. I would like to add just a few thoughts. Machine-actionable tools and services are accompanying everything; they are needed for consensus and should be available. Then, there is the human factor behind it. For humans, translation services are really important. Most are based in English. Maybe we should rethink how we can translate services offered to all populations in all regions of the world according to the way they talk or understand. The third thought concerns the (open science) repositories—easy access to repositories not only to access the results of science but also to have easy access to deposit data. This will enable open science. Of course, it costs, but it is better to pay for this.

**SHEARER:** In terms of infrastructure, I think we need to achieve a kind of careful and complex balance to support international collaboration and information sharing but also the different functionalities that might be required by different domains. Infrastructure may support different languages, as Paolo said, but also research priorities. I'm concerned about having infrastructure that is too centralized because those types of infrastructures tend not to support local priorities and local languages; yet we also really want to have distributed infrastructures that are interoperable.

We need to keep in mind that there are inherent biases in infrastructure development, especially in research communities. Leslie Chan and his research group have written a lot about this. Most infrastructures are developed in the global north and, therefore, contain the inherent biases and priorities of the global north. I think that's why what Omo is doing, for example, in Western and Central Africa is so important—developing and adopting infrastructure for their own local needs. Roberto spoke about FAIR and the importance of FAIR data, but I think we also need to keep in mind sustainability, preservation, and trust as part of our perspective and our principles around developing infrastructure.

So, who owns and manages the infrastructure? Is it based at long-lived organizations? Is there a commitment for long-term preservation and access to the content that's being managed there? All of this costs money—how will this be funded and maintained over time? We need to start thinking about scholarly communication infrastructure like we think about any other type of research infrastructure and fund it accordingly. There's already some money in the system. If you think about the billions of dollars every year spent on purchasing scholarly journals, could this be repurposed for open infrastructure? We need a kind of path forward to be able to transition those funds from where they are now into infrastructures that can support open science.

**OAIYA:** From the African perspective, there needs to be a facility to have services that are contextual in each region. That involves interaction with other stakeholders not directly related to the education and research community. These are additional hidden costs as they require time and effort to surmount the challenges in getting those people on board with these ideas. Paolo mentioned constitutions with statements about science and research. In most African countries, the same applies, but there's a mindset that is more focused on everyday issues—you know, bread before science: am I going to build a new road or invest in national infrastructure to support open science? One of the costs, then, is investing in getting these decision makers and policy makers to appreciate the benefits of open science.

**LOPER:** While the type of work my organization does is not always considered open science, there's definitely a recognition among the customers we serve that a more open science approach is beneficial to them. For example, their ability to share costs, increase the usability of infrastructure and platforms, and increase the utility benefit of the infrastructure—they think about infrastructure not just as platforms and data but models, algorithms, policies, interfaces, and process metrics from a broad perspective. They are finally understanding that they can either build these infrastructures over and over again as proprietary environments and spend huge amounts of money and time to do that, or they can take an open science approach to how they develop these platforms. They recognize that giving up proprietary ownership will give them a greater benefit in the long run of lower development costs, because the cost is shared. There are good examples of this from a U.S. national perspective, where people are starting to see this benefit. There's always hidden costs, but data interoperability is important. We see a lot of growth in that space. How do we leverage those good national and international examples?

**UHRMACHER:** Publishers are currently enhancing their platforms and processes to accommodate the products, such as data and software, that may accompany the open access publications. If we do not want to rely on publishers for platforms and services, the costs for maintaining such platforms and services need to be covered elsewhere, as Kathleen has already stated.

***COMPUTER*:** What about ethics and open science?

**BUDRONI:** It's a complex question. Nowadays, when we talk about ethics, we refer to the ancient Greeks. We refer to concepts that were discussed more than 2,000 years ago. In that time, scientists like Archimedes used their senses to produce science and the actions they would like to undertake. This was the way they interacted directly with the world.

This mechanism is very similar to what we do now. Scientists observe. We have, for example, machines equipped with sensors that have some specialized function or mechanism, such as machine-actionable sight or digital hearing. Testing, smelling, touching—all digital. A machine receives and responds to external or internal impulses. Two thousand years ago, the scientist could cover all of these processes alone. Now, although the mechanism is very similar, we cannot do this for the simple reason that, between a scientist and the world, there is a huge layer of data, and software is needed to filter these data. There are many people involved in the creation of data, software, and so on and many people affected by the decisions made by scientists.

We need clear and understandable rules that are recognized and accepted by everybody. We define these as a legal framework, but laws without ethics are like an intermittent way of talking. Science must walk quickly to its target. We need legal frameworks with ethical guidelines—moral principles that govern a scientist's behavior as well as the conduct, tools, supporting services, and community infrastructure used in scientific activity.

**SHEARER:** Basically, I agree that an ethical framework is important. I'm particularly concerned with the social discussion about fake news and that creeping into the scientific realm. We could lose the legitimacy or perceived legitimacy of science. We really need to think about how we can create the mechanisms to ensure that there's public trust in science. This has always traditionally been done through the peer review processes, and I think those will continue to be important. We have to balance that with some of the objectives of open science, which is to try to speed up the rate at which we can share information. So, can we develop some assessment mechanisms for other types of shared research outputs, a broader range of content, than are available through our open infrastructures?

I have a kind of another slightly different take on the ethical aspect, which is one of my concerns and the concerns of my organization. It is the impact of the way open science rolls out in developing countries, in particular, when it comes to open access. Are we going to end up with a pay-to-publish model for publishing articles, and what will be the impact on researchers and developing countries or less-resourced researchers around the world? If they have to pay to have their articles published, that will be a huge barrier. I think there's this whole ethical framework of our principles around open science that needs to look beyond just openness. We need to think about how we create a trusted landscape, a trusted ecosystem, that also is inclusive and sustainable and supports diverse priorities and needs. A consultation that was recently launched by UNESCO will, hopefully, bring out some of these other important underlying principles for a truly global ecosystem related to open science.

**OAIYA:** Aside from the pay-to-publish concerns, which just basically disadvantages developed countries, there is the increased issue of trust, especially if open science becomes freer—is what you access the right quality? There's also been an increase in bogus journals that publish articles that cannot be certified. Another challenge in African institutions is where researchers publish. Within their institution, there's a mandated requirement to publish as well as a link to promotion. From that point of view, if there were an open science framework, then the decision makers would be able to connect to that and make it a little easier for the researchers.

**LOPER:** Yes, I think there should be an ethical framework. Obviously, there are sets of criteria for reviewing papers and making the reviews open so that people who read the papers also see the reviews. How can you extend that across the other dimensions of intellectual property and science, and how do you make that understandable in a way that people can trust? We know there are people and organizations that try to create science to address their belief or position and try to influence political decisions.

We're seeing that with the coronavirus. They do this to create dissent, disinformation, and so on. This happens in countries, in companies, and in industries—they try to sway public opinion through citizen science and blogging. There's a whole area around ethics and trust. How do you trust what that science is saying, and how do you communicate it to people in a way that they can trust?

For example, with the coronavirus, we get all of these results out of different models that say different things. As scientists, we understand why different models give us different answers, but people who are not scientists don't necessarily understand that, so they have this misbelief in what they're hearing. People can use these differences to influence people in political directions for their advantage.

**BARBERA:** Yes, there is a need for an ethical framework. If we are concerned, for example, with data concepts of privacy, provenance, curation, and anonymization, then one should be in place to ensure whatever we share is trusted and consolidated and that we minimize the fakeness of the contents to share. This brings us to the need of open science policies, which is another big topic in the open science landscape. Very few countries in the world have an open science policy with an ethical framework.

More technically, I think that an ethical framework is also connected to the authentication and authorization infrastructure used to access data in terms of the *A* of FAIR. In this respect, the international research community has made gigantic steps in federated authentication. There is the eduGAIN infrastructure (eduGAIN gives single sign-on access for educational services at https://www.edugain.org), and there are identity federations in (almost) all countries, which are managed by national research and education networks. However, little has been done on homogenizing these. This is important, as it has an impact on how we access research outputs.

> We need clear and understandable rules that are recognized and accepted by everybody.

**UHRMACHER:** To ensure the quality of these open products, or the reusability, *R*, in FAIR, is a big challenge and closely related to the ethical values of scientists providing and reusing these products. The question is how misconduct will be penalized or prevented from the outset, for example, by establishing reviewing, curation, or authorization processes.

***COMPUTER*:** How is open science being adopted?

**SHEARER:** I think open science, right now, is kind of a top-down movement rather than bottom up. Policies have become important levers for advancing open science. Many countries and regions have adopted open science policies, but they are not necessarily harmonized across different jurisdictions. I think many of the differences between the policies internationally are related to the availability of resources of different countries. Most importantly, open science policies are really still in conflict with the incentive systems in place at universities and with governments and funders. While open science policies are trying to incentivize open practices and the sharing of information, incentive systems are still prioritizing publishing and prestige journals, patents, and commercialization.

I'd like to give you an example of where policies are different across different regions. Open access policies (one part of open science) require articles to be made openly available. There's kind of a northern approach to policy development and a southern approach. The northern approach has really been to continue to rely on commercial publishing companies and kind of flips from subscription to open access. The southern approach has been to develop its own local infrastructure to support open access. We see this in Latin America and, increasingly, in Africa. These two different approaches are fine, except that it's usually the northern approach that wins out and has an impact on policy requirements in the north. This, then, has an impact on researchers in the south. We have to be very careful and ensure that the policies we're adopting in the north are sensitive to the needs and requirements of southern countries as well.

> Very few countries in the world have an open science policy with an ethical framework.

**OAIYA:** We're in the very early stages of promoting the adoption of open science policies. Apart from a few examples in Africa where there's a concerted effort, we're still at the stage where we're working with templates trying to make the arguments. We work with what Kathleen Shearer mentioned as the southern approach, as we're in a situation where there's very little research coming out of Africa because of the way the landscape is laid. We are trying to lay out open science infrastructure and advocating policies that are aligned with those infrastructures as well as trying to make the argument about why we need to see if we can actually establish an open access identity that is more contextual (to Africa).

**LOPER:** We do a lot of work for the U.S. Department of Defense. We've seen their policies change to be more open. They have found that having one contractor or a set of contractors develop things for long periods of time has not always led to the kind of agile response, innovative thinking, or robust output that they want. This can lead them to being locked in to a particular solution. Now, they are adopting more open science practices, and they have definitely seen great benefits. They can fund a diverse set of organizations to do different work on their open platforms. It has helped them to realize the benefits of emerging techniques, processes, and development practices that they didn't have before. They've also been able to better incorporate small businesses and individual contributors versus big, large-industry organizations.

They're also starting to really understand the benefit of owning their data—this means that they (the government) can give it away freely to who they want versus having a contract with somebody who owns data and has some restriction on its use. In one particular area with the U.S. Department of Defense, we've seen willingness to adopt open science approaches to common infrastructures, common models, open data, and well-understood interfaces leading to better approaches to the interoperability of existing systems. It's beneficial to them and to researchers who want to contribute, as the old system created barriers to entry.

**UHRMACHER:** In Germany, the major funding agencies, such as the Deutsche Forschungs Gemeinschaft, encourage scientists to publish open access and make other products of their research available to the community. The Winter Simulation Conference (https://www.wintersim.org) has been publishing its proceedings as open access traditionally. Papers of all but the first conference in 1967 can be accessed easily, which is quite amazing. Meanwhile, journals and conferences in computer science and also in simulation have started to offer authors the opportunity to have the results of their papers replicated, and their artifacts (such as software or methods) evaluated, whether being functional, reusable, and accessible. If successful, the author's paper receives specific badges, and as an incentive for the reviewers and to make the reviewing process transparent, details of the replication and evaluation process are published as short reports within the journals and proceedings. The later initiatives are often started by individuals, editors-in-chief, or program chairs. So, it seems a mixture between bottom up and top down—maybe, simply, middle out.

**BARBERA:** The uptake of open science is almost exclusively bottom up. There is a growing number of researchers and groups, even large groups, quickly adopting the open science paradigm, especially with the emergence of COVID-19. In very few cases, this bottom-up approach is backed by a top-down approach. Very few countries have open science policies officially endorsed by national governments.

There are some strong initiatives that are forcing change. Staying with open access, Plan S is quickly evolving, and there are already a few tens of national funders that have signed the Plan S agreement. for example, U.K. Research and Innovation, the

Italian National Institute of Nuclear Physics, and so on. (Plan S is an initiative launched by a group of national research funders supported by the European Research Council and the European Commission that aims to make full open access a reality.) I think Plan S will change something, and it will come into force from 1 January 2021 with the aim of quick open access publishing without any embargo.

One approach Plan S suggests is the so-called green way that uses open access repositories. This will be a good opportunity to improve open access repositories and the e-infrastructures we discussed earlier. I agree with Kathleen, and I reinforce the suggestion that open science is very difficult without changing the way we evaluate research and the way we reward and incentivize the researchers. It is changing. Organizations are signing up to the San Francisco Declaration on Research Assessment (https://www.sfdora.org), which focuses on alternatives to research quality assessment, not just metrics.

I'll end with a success story. A couple of years ago, we were asked by the Ethiopian Government to set up a national academic digital repository[7] for publications first and then for data. We worked for two years to make this happen. The repository is now in place and used to store theses, publications, and so on. In 2019, this triggered the decision by the Ethiopian government to adopt a national policy on open access.[8] Ethiopia is one of the few countries in Africa that has such a policy, and all Ethiopian universities are committed to it. There are good signs that decision makers are moving toward embracing open science.

**BUDRONI:** Since I'm based in Europe, I would like to treat this argument from a local perspective. There is an increased awareness of the need for open science policies. In my opinion, here in Europe, this is mainly due to three factors: the Budapest Declaration on Open Access,[9] the upcoming European Open Science Cloud (EOSC),[10] and the European Union legislations concerning open data, General Data Protection Regulation, and Public Sector Information Directive. These three factors shape the development of open science, and the EOSC is one of the most relevant outcomes of this process. We see more initiatives coming in Europe and beyond—OpenAIRE,[11] LEARN,[12] and so on.

A principle is a fundamental truth or proposition that serves as a foundation for a system of belief or behavior in a chain of reasoning. If I said you should not delete scientific data, the principles that are derived from this are that open science data are to be kept FAIR—findable, accessible, interoperable, and reusable. Similarly, another principle is that open science infrastructure should be maintained to provide the necessary support. I have then to conceive the rules—the rules that offer regulations to these principles. This is better if it is generated bottom up because this then results from the action of individuals. We can also see policies, which are generated from the top as an action of an executive. Either way, we need to understand the differences between principles, policies, rules, and regulations.

***COMPUTER:*** So, should all science be open?

**OAIYA:** I think science should be as open as possible and closed when it needs to be. There should be some control by the producers and their administrative bodies. On a broader basis, good research data practices should be mandated, for example, such as in research data management plans. There should also be mandatory equitableness in partnerships so that weaker partners are not disadvantaged. It is essential for global innovation.

For example, with COVID-19, the speed at which innovations are occurring is being driven by available data and scientific output. Also, recently, as part of the AfricaConnect project,[13] which is connecting research organizations in Africa, we have been talking to RUFORUM[14]—a network of agricultural institutions and research organizations across Africa. The conversation is centered around leveraging this network to establish a knowledge hub that collates all information and data to produce a collaboration platform. We see that, with the right policies, we would leverage agriculture in ways that don't currently exist to address Sustainable Development Goals. Again, this comes from the basic concept of openness.

**LOPER:** I agree that open science should be as open as possible. I don't think that unfunded mandates work. So, just coming in with a heavy hammer and saying it is all open science will meet with great resistance. With some of the customers that we serve, for example, in defense, it doesn't make sense. It makes sense for them to be open within their set of problem spaces that they can control and protect.

Moving toward open science has to be more of a gradual process. Can it help with global issues? Absolutely. We are seeing in the work that we're doing related to the coronavirus that an open science approach is helping to be more responsive and agile to addressing needs with the platforms, environments, and frameworks that we have created for problem solving. I definitely think open science can be used to solve greater world problems, like pandemics and sustainability. We have to have some ethical or trust framework, as open science could be vulnerable to someone with malicious intent. We also need incentives and case studies of what has been successful to help people understand why open science is beneficial to them and society at large.

**UHRMACHER:** It has been stressed already that making artifacts accessible is not sufficient for research and its products to be interpretable and reusable. This requires additional efforts and time. As Margaret has already stated, not all research must adopt open science. Still, I would like to see some justification in these cases. Open science should become the norm rather than the exception, as it would make M&S research more sustainable and facilitate scientific progress.

**BARBERA:** The uptake of open science should come from bottom up, from the researchers. This is happening. The long-term sustainability of open science practices should be regulated by the government through incentives for researchers and changes in the process of research and innovation. This needs regulation; otherwise, open science will be perceived as not the main way of doing research that will bring you to the highest level of your career.

Open science is very important for tackling multidisciplinary problems. The COVID-19 emergency is demonstrating this. Open science is the way to tackle the United Nations' 2030 Sustainable Development Goals. From the technical point of view, if we are addressing multidisciplinary problems, then you have the big problem of homogenizing metadata. There are working groups that are discussing how to do this. If you can, then you can really have a semantic web layer that could enable multidisciplinary, cross-disciplinary searches and analyses.

**BUDRONI:** Two comments. The first—let us open science using "open" as a verb—science should be opened. The second—starting again from the point of view of ethics, ethics is not only important in open science, but it should be the source of innovative activities. Open science does not need unethical tools. My recommendation would be to focus on ethics, especially as there is a new branch of ethics concerned with the responsible use of data and algorithms in corresponding practices that serve open science (such as the discussions that are taking place in artificial intelligence).

**SHEARER:** I agree with the others that much of science can and should be made open. Everything that is already being published should be open. It's already out there, and it should be open. Of course, there will be exceptions for things like personal and sensitive data. Indigenous knowledge is very much on our minds here in Canada and respecting the ownership of indigenous knowledge. I think we need to build this ethical framework that we discussed earlier around the whole ecosystem of open content. There's an issue of resources related to making things open. There is a pragmatic challenge around describing data and the efforts that it makes that are needed to make data FAIR. In some jurisdictions, in some cases, we may need to think about what our priorities are in terms of data sharing and focus on those priorities.

In general, I think open science is very important for addressing some of the most important challenges we have, including climate change and the pandemic we're in right now. I think open science contributes to every one of the Sustainable Development Goals, and so, as much as we possibly can, we should try to make to make our scientific outcomes open. C

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