

Open Science and Epistemic Diversity: Friends or Foes?

Sabina Leonelli

University of Exeter, St Germans Road, EX4 7HD Exeter, UK

& Wissenschaftskolleg zu Berlin, Wallotstrasse 19, 14193 Berlin, Germany

s.leonelli@exeter.ac.uk

Abstract

I argue that Open Science as currently conceptualised and implemented does not take sufficient account of epistemic diversity within research. I use three case studies to exemplify how Open Science threatens to privilege some forms of inquiry over others, thus exasperating divides within and across systems of practice, and overlooking important sources and forms of epistemic diversity. Building on insights from pluralist philosophy, I then identify four aspects of diverse research practices that should serve as reference points for debates around Open Science: (1) specificity to local conditions, (2) entrenchment within repertoires, (3) permeability to newcomers and (4) demarcation strategies.

Keywords: pluralism, inequity, data, reproducibility, software, collaboration, science policy.

“The empirical question is how belief, commitment, or theory and hypothesis acceptance are stabilised in the face of openness of inquiry. The normative question is how they are stabilised in a nonarbitrary way that has probative value”

Longino 2002, 205

Introduction

The potential of Open Science (OS) to enhance research quality, integrity and societal impact has been widely discussed within academic and policy circles over the last two decades, and has been underscored by the rapid development of COVID-19 treatments and vaccines – an extraordinary scientific achievement which was arguably only possible through the immediate sharing of results around the globe. The effectiveness of disseminating results promptly, sometimes even before having them formally published – thereby speeding up research - has been extolled by scientific and popular media alike, most evidently in relation to the prompt dissemination of genetic sequencing data from various strains of the SARS-COV-2 virus (an exemplary instance of ‘Open Data’) and the decision by publishing companies to temporarily release all coronavirus-related papers without charges (‘Open Access’).¹ As the United Nations joins the choir of OS supporters with its 2021 recommendation to implement OS worldwide, the OS movement looks well-positioned to determine the future of post-pandemic research and related policies.

What this may mean on the ground is less clear, given the many competing views on what OS practices may involve (Fecher and Friesike 2014, Levin et al 2017). In what follows I focus on the vision of OS proposed by the European Commission in 2015, which defined it

¹ I examined these developments in Leonelli (2021) and Krige and Leonelli (2021).

as “a new approach to the scientific process based on cooperative work and new ways of diffusing knowledge by using digital technologies and new collaborative tools”. In this view, OS constitutes a positive development for the scientific landscape, whose implementation automatically improves the outputs of research as well as researchers’ working conditions. OS is presented as tightly linked to the digital transformation of research, and thus as a novel phenomenon that is dependent on the availability of information and communication technologies.² OS is also presented as a global phenomenon focused on providing unlimited access to any research element, at any point of an investigation, to anybody with an interest in research, no matter where they are based and whether or not they are professional researchers. OS is thereby taken to facilitate equity and inclusivity in research production and consumption, by making previously inaccessible resources available to anybody interested in participating in research. An underpinning belief for this vision is that principles such as collaboration, transparency, reproducibility and openness are constitutive of good scientific practice, regardless of the specific conditions under which research takes place (Burgelman et al 2019).

Despite vast efforts to implement OS thus defined, it remains unclear how this vision relates to the widespread diversity in epistemic practices and cultures characterising research, as richly documented by historians, sociologists and philosophers of science (e.g. Knorr-Cetina 1999 and Kellert et al 2006). Most OS policies support the adoption of common metrics, standards and platforms, seen to facilitate communication among researchers and foster the effective sharing of data, models, software, ideas, materials, methods and whatever else happens to be produced in the course of an investigation (United Nations 2019). It is

² Note that the emphasis on the novelty of OS runs counter historical evidence of long-standing collaborative and sharing practices within some scientific domains. (e.g. Strasser 2020).

sometimes acknowledged that “one size does not fit all” (Open Science Policy Platform 2018) and there are substantive efforts to develop “intelligent” approaches to openness and understand what OS involves within different research contexts (e.g. Boulton et al 2012 and long-standing work by the Research Data Alliance). Nevertheless, national and international policies tend to implement OS guidelines, tools and principles in a top-down manner and across domains, with some attention paid to disciplinary cultures but no fine-grained consideration of the diverse capacities, motivations and methods characterising different epistemic communities.

By contrast, this paper argues that understanding the epistemic roles played by different forms of diversity within research, and particularly differences that go beyond the well-recognised and institutionalised boundaries between disciplines, is crucial to the implementation and the conceptualisation of Open Science - and that philosophy of science can contribute foundational insights towards developing such a framework. Building on consideration of three empirical examples, the first part of the paper illustrates how an overly standardised and generalised conceptualisation of OS and its implementation threatens to privilege some forms of inquiry over others, thus exasperating divides within and across systems of research practice. I highlight the complex interrelations among multiple sources of diversity of relevance to OS, and the difficulties in adequately addressing such interrelations through universal policy frameworks or appeals to disciplinary differences. Taking inspiration from philosophical literature on scientific pluralism, the second part of the paper proposes an alternative foundation for debates around Open Science, which focuses on the following characteristics of research: (1) *specificity* to local conditions and targets; (2) degree of *entrenchment* within existing repertoires; (3) degree of *permeability* to epistemically relevant newcomers; and (4) *demarcation strategies* to determine whether results can be

reliably regarded as scientific contributions, and who is involved in such decisions. I conclude that unless OS advocates embrace a more sophisticated understanding of epistemic diversity grounded on these insights, OS policies risk acting as a reactionary force reinforcing conservatism and inequity in research.

Openness in scientific practice

I start by briefly considering three scientific debates which exemplify both advantages and challenges of promoting openness across a wide range of research practices and locations.

Case 1. Open versus equitable data access

The first example concerns the Global Initiative on Sharing All Influenza Data (GISAID), a platform for transnational data sharing that rose to international prominence during the COVID pandemic. GISAID was launched in 2008 in order to share data of relevance to studying influenza and was swiftly modified in 2020 to include data on SARS-COV-2. Contrary to other initiatives in molecular biology, which have long placed a premium on sharing of genetic sequences without any constraint (Maxson Jones et al 2018, Strasser 2020), GISAID requires anybody who wishes to access the database to sign a user agreement, which includes assurances about adequately acknowledging the original data producers. This requirement stems from the recognition that some researchers – often working in low-resourced environments and/or less visible research locations – are reluctant to share data due to fears of better-equipped researchers building on such work without due acknowledgment. Such fears are well-justified. Re-using data available online requires reliable and powerful connectivity and computing resources, as well as the adoption of standards typically built to match the theoretical perspectives of laboratories in the Global

North. Hence researchers based in low-resourced environments cannot easily take advantage of Open Data, no matter how innovative and rigorous their work may be, and remain reluctant to contribute their own data to online collections.

GISAID was built with the recognition of entrenched differences in power, resources and visibility among research groups, and its data governance structure actively tries to counter postcolonial asymmetries between researchers based in the Global South and the Global North. Indeed, having a formal agreement and credit structure in place has proved remarkably effective at fostering trust and information exchange among groups that differ considerably in their geo-political locations, funding levels, material resources and social characteristics. And yet, despite this success and the many discoveries resulting from the opportunity to share data on virus strains across hundreds of research sites, GISAID has come under a barrage of attacks for “not being open enough” and posing “barriers that restrain effective data sharing”, particularly by researchers and institutions based in the Global North.³

The debate over GISAID and its governance structure exemplifies how efforts to abide by the principle of openness, particularly when it comes to Open Data, can clash with responsible research measures geared towards protecting researchers whose work is unrecognised and/or discriminated against. In this as in many other cases, providing trustworthy and explicitly non-exploitative conditions for data sharing helps to widen participation in data sharing, which in turn expands the evidence base for subsequent discoveries. It also helps prevent the circulation of low-quality data (Leonelli 2018a), the expansion of digital divides (Bezuidenhout et al 2017) and socially harmful research (Elliott and Resnik 2019). In choosing to sidestep these issues, researchers calling for “fully open”

³ See Open Letter (2021), which was subsequently reported in *Nature*.

data are discounting the significance of socio-cultural factors (such as the geo-political location and characteristics of researchers), institutional issues (such as power dynamics among research sites, expectations around intellectual property) and infrastructural resources (such as the availability of funding and dependable connectivity) to data re-use.

Paradoxically, this may result in excluding some researchers from data sharing initiatives, which reduces the diversity and range of data available online, thereby constraining the evidence base for evaluating existing knowledge claims and developing new ones.

Case 2: Free versus proprietary research software

Already in 2011, Harding noted that “gone are the days when it could appear uncontroversial to assume that Western sciences are or have ever been autonomous from society, value-free and maximally objective, or that their standard for rationality is universally valid” (2011, x). This diagnosis rings ever truer given the rise of China and India as scientific superpowers and the ever-growing scientific workforce in many other non-Western countries. And yet, regimes of assessment, credit and quality control set up by rich Western institutions continue to rule academic rankings and evaluation regimes. It should thus come as no surprise that the understanding and implementation of OS is largely grounded on ideas forged within privileged research locations in the Global North. Another case in point concerns the extent to which research work is assumed to depend on access to specific technologies, and the repercussions that such assumptions have on research evaluation.

As an example, consider the importance assigned by OS to open source research software, which can be accessed and modified freely, thus posing no barriers to its adoption – contrary to the expensive subscriptions required by proprietary software. This requirement

may seem uncontroversial until one looks at how researchers in low-resourced environments select and use software to support their work. Indeed, the Global Young Academy carried out a survey among researchers in Bangladesh and Tanzania, which demonstrated a strong preference for using expensive proprietary software (Vermeir et al 2018). This was confirmed even in cases where equivalent open source alternatives were available and obtaining funds to pay for proprietary tools was difficult if not impossible. The reason for this preference was the perceived stigma attached to using open software. Participants in the study claimed that using open software was perceived by editors and referees of international journals as a mark of low-quality research, particularly when coming from research locations with little international reputation. Using well-recognised proprietary software such as *MatLab* and *Mathematica*, by contrast, was seen to align with international expectations around appropriate methodology, thus facilitating publication of research results by Anglo-American journals. Similar arguments have been made around quality assessment for datasets, which is often seen to depend on the technology used to produce the data – with the latest models of genome sequencers, for instance, taken to generate better data than earlier, cheaper models (Leonelli 2018a).

When taking such findings into account, OS tools only look effective within specific types of well-resourced research environment, to the exclusion of others. The preference for specific technologies turns out to depend on factors other than the suitability of that tool to the scientific tasks at hand. Such factors may be infrastructural, such as the availability (or lack thereof) of appropriate training and support for adopting a given technology; institutional, including the structure of scientific publishing and the powerful role played by referees and editors; and socio-cultural, like the reputational hierarchies characterizing each field and the assumption that rich labs should act as role models for other research sites.

Notably, these factors affect the type of research being conducted, with researchers refusing to explore potentially useful tools due to the perceived stigma attached to their use. They also inform collaborative strategies, as researchers who do not have access to resources perceived as essential for international publishing often choose to partner with richer institutions who may provide such access. While open source software is recognized as valuable in theory, its use in practice clashes with existing - and sometimes conflicting - assumptions about what counts as reliable science, and who gets to decide.

Case 3. Reproducibility in action

To further underscore the methodological and conceptual implications of researchers' adoption (or lack thereof) of OS practices, and the key role played by social and infrastructural factors in shaping that process, I now briefly consider the raging debate around the principle of reproducibility. Reproducibility, understood as the ability to replicate a given piece of research in ways that yield consistent results thereby corroborating their validity, is often presented as a pillar of OS, whose key function is to help decide which research results are credible and which are not (Burgerman et al 2019). Reproducibility thus acts as a criterion to distinguish science from pseudoscience, with non-compliant research being viewed as unreliable at best and arbitrary at worst. Highly controlled and standardised experiments with pre-specified goals, such as randomised clinical trials or gene knockout experiments on model organisms, constitute well-recognised instances of reproducible research and are held up as a model for good research practice more generally. Notably, the data produced through such controlled settings are also among the easiest to share and re-use, given that they are often obtained in digital form and accompanied by consistent metadata (Leonelli 2018a). Where does this leave research settings where controls and standards are

not as well-developed, and where in fact the nature of the phenomena being studied demands few if any such controls and standards?

Philosophers have noted how reproducibility takes different forms and meanings depending on the specific cluster of methods, settings, data types, targets, conceptual assumptions and goals that turns out to be of relevance to each scientific project (Radder 1996, Guttinger 2020). Even within the same discipline, there can be dramatic differences in the significance ascribed to replicating a computer simulation, where control over research settings is so high, given their artificial nature, that both procedures and results are expected to be fully reproducible; field-based observations, where there is little control over research settings, and what is reproduced are observational skills rather than the results themselves; or data obtained by exploratory experiments where conditions vary during and across experiments, generating variations that are often the starting point for new investigations (Leonelli 2018b, Feest 2019). Taking highly controlled experiments as models for best practice in reproducible research, against which other forms of research are evaluated and results are demarcated as more or less credible, can therefore be damaging. Just like attempts to enforce openness regardless of the context, efforts to support reproducibility as demarcation strategy across all scientific domains side-step the variability in the methods developed to suit specific goals, concepts and target objects – as well the broader conditions for research work.

Sources of epistemic diversity

Even in this simplified form, these examples point to the variety of elements involved in the implementation of OS principles and tools, and the different ways in which such elements can be clustered and aligned within specific situations of scientific inquiry. Each

example presents some respects in which research situations may differ from each other, which are relevant to the implementation and conceptualisation of OS, and which I listed in Table 1.

<p>MATERIAL</p> <ul style="list-style-type: none"> ▶ Target objects ▶ Materials <p>CONCEPTUAL</p> <p>METHODOLOGICAL</p> <ul style="list-style-type: none"> ▶ Standards ▶ Methods <p>INFRASTRUCTURAL (capacity res. environment)</p> <ul style="list-style-type: none"> ▶ Funding ▶ Infrastructures ▶ ICT and other technologies ▶ Mobility and transports 	<p>SOCIO-CULTURAL</p> <ul style="list-style-type: none"> ▶ System of research assessment (locally and nationally) ▶ Legal and ethical accountability ▶ Geo-political location ▶ Language ▶ Values and goals ▶ Characteristics of researchers (gender, class, ethnicity, age, physical ability..) <p>INSTITUTIONAL</p> <ul style="list-style-type: none"> ▶ Career stage and power dynamics ▶ Institutional and administrative support ▶ Field of study and related norms / venues for publishing and exchange ▶ Intellectual property regimes
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Table 1. Sources of epistemic diversity of relevance to Open Science, classified under six umbrella categories: material, conceptual, methodological, infrastructural, socio-cultural and institutional.

The relevance of these scientific components to knowledge production, and the variability among them, have been amply discussed by scholars of science including philosophers, historians and sociologists. There are two aspects that I wish to underscore here. One is the profound significance that different alignments of infrastructural, methodological, conceptual and institutional sources of diversity can have for the implementation and understanding of OS. This is worth emphasizing since some of these factors are not usually regarded by philosophers as having epistemic import, and it is sometimes assumed that conceptual or methodological issues can be considered and evaluated in isolation from social or material elements such as institutional settings and

infrastructure. And yet, the examples above highlight the crucial role played by infrastructural, institutional and socio-cultural factors in determining not only the conditions of possibility for research, but also the criteria used to evaluate its procedures and results. In that respect, the elements in table 1 function as sources of *epistemic diversity*, defined as *the condition or fact of being different or varied, which affects the development and/or understanding of knowledge*.⁴

Another significant aspect is the capillary, highly situated nature of epistemic diversity, as evidenced by the local variation encountered even within the same disciplinary spaces. The use of disciplines to capture differences in methods and traditions does not capture the high variability displayed by research performed at different locations and with different perceptions of what constitutes best practice and who is responsible for adjudicating it. Most importantly, it does not capture the diverse ways in which researchers may pick and align specific elements to confront a given situation of inquiry. This is especially notable given the global increase in interdisciplinary and transdisciplinary research efforts aiming to confront systemic challenges such as climate change, pandemics and population growth: within such multi-perspectival projects, understanding OS and its implementation involves a finer-grained analysis of differences among research groups than that offered by the broad categories of ‘discipline’, ‘domain’ or even ‘field’. To this aim, I shall use Chang’s idea of *system of practice*, which denotes any “coherent set of epistemic activities performed with a view to achieve certain aims” (2012, 16).

⁴ This definition is an adaptation of the definition of diversity provided by the Cambridge English Dictionary.

Systems of practice: what matters for OS?

Philosophical debates on scientific pluralism have provided a wealth of insights on what characterizes ‘the condition or fact of being different or varied’ among systems of practice and what makes such differences epistemically salient (‘affecting the development and/or understanding of knowledge’). I now discuss four such insights as particularly helpful to conceptualize and implement OS in ways that valorize, rather than undermine, epistemic diversity.

First, as evident from Chang’s definition, systems of practice differ in their *specificity* to local conditions, targets and goals. At their best and following iterative refinement over time, research strategies and tools are exquisitely tailored to suit the specific characteristics of the phenomena under investigation: hence methods, theories and models differ depending on their suitability to target object(s) (Mitchell 2014) and the availability of materials exemplifying that target (Chapman and Wylie 2016). Moreover, research agendas and strategies are adaptive (Nersessian and McLeod 2013) and responsive to the inherent instability of targets (Feest 2017). Rather than assuming stable targets, generalizable approaches and standard methods to be desirable components of good research practice, OS thus needs to value the system-specific and dynamic features of local research settings and results.

Over time, some systems of practice acquire a reputation for being more reliable, easier to mobilise and/or more productive than others (whether due to their effectiveness in achieving goals, the robustness of their methods, their suitability to existing policies and institutional settings, and/or other factors). Such systems of practice, including the relevant clustering of values, beliefs, institutions, methods and goals associated to the study of given

phenomena, thereby become entrenched as “gold standards” for research concerning those phenomena. In some cases, this results in a system of practice becoming institutionalised as a research field in and of itself. In others, systems of practice become what Ankeny and Leonelli (2016) call *repertoires*: ways of doing science that do not align with disciplinary boundaries, but retain a strong influence as blueprints that can be easily adopted and are implicitly recognised as effective and reliable. The use of randomised controlled trials, and related understandings of reproducibility, is a case in point; model organism research, and its associated ethos of data sharing as needing to be free of constraints and governance structures, is another (Ankeny and Leonelli 2020).

In principle, good research can be construed as involving the freedom to consider which system of practice may be best suited to investigating given questions and targets (whether such a system already exists or needs to be developed). In practice, there are strong incentives to redeploy existing repertoires, not least because such mature systems of practice tend to have a standardised structure (including well-developed OS infrastructures) and require less work than the creation of a new system. The extent to which standards for making or evaluating research are embedded in a wider repertoire is highly relevant to OS. Indeed, the second insight I want to underscore is that systems of practice differ in the degree to which they are *entrenched within existing repertoires*, and thus the degree to which researchers are free to select and develop systems of practice that are specific to their target objects.

The specificity and entrenchment of systems of practice, when considered together, present a problem for OS. The standardisation and redeployment of existing resources, including data and software, is a central aim for OS; but it is also a key avenue by which

systems of practice lose specificity and epistemic diversity. Indeed, researchers working with a system that is highly entrenched within existing repertoires may not value – or even consider – elements that are not already part of that repertoire. In other words, systems of practice differ in their *permeability to epistemically relevant newcomers* (whether these be ideas, methods, people, technologies or research sites), thereby challenging the appeal to openness and inclusivity that underpins OS policies.

Pluralist philosophers have long pointed to the danger that excessive conservatism and exclusionary logics present to the robustness of knowledge claims. For instance, Longino highlighted the conditions under which results are publicly scrutinized as critical to the quality of that scrutiny: “not only must potentially dissenting voices not be discounted; they must be cultivated” (2002, 132). Exclusions based on social conventions embedded in specific institutions, such as the above-mentioned perception of open software as less likely to be favorably reviewed, are particularly damaging since they do not have a scientific rationale and yet they have powerful epistemic implications. OS practices need to explicitly and actively challenge the dominance of long-standing repertoires and encourage inclusivity, even where this complicates attempts to develop common standards and infrastructures.

This brings me to my fourth and final point, which concerns the *demarcation strategies* used within any one system of practice to determine whether results can be reliably regarded as scientific contributions, and who should be involved in such decisions. Whether such demarcation strategies are implicit assumed or explicitly discussed, their development and adoption by researchers is arguably an unavoidable part of creating and maintaining a system of practice in the first place. By setting criteria for what constitutes proper science and what does not, and which forms of expertise are deemed to be relevant, demarcation

strategies provide the glue that brings and keeps epistemic activities together – what makes systems of practice coherent, in Chang’s terminology.⁵ This was famously recognised by both Popper and Kuhn, though Kuhn’s paradigms failed to capture the fine-grained nature of such decisions and Popper dismissed the normative relevance of factors other than conceptual and methodological. What this teaches OS is to exercise caution with indiscriminate appeals to general principles or procedures, and ensure that debates around OS implementation within any one system of practice include explicit and regular consideration of existing demarcation strategies.

Conclusion: Ways forward for a pluralistic OS

I argued that a key challenge for OS is to productively manage the clash between different interpretations and operationalisations of openness, which emerge from diverse systems of practice. Far from constituting an obstacle to the implementation of OS, consideration of epistemic diversity can help to realize the aspirations of the OS movement, while at the same time providing an opportunity for OS to avoid capture by dominant research repertoires and defy inequitable, conservative and flawed approaches to research.⁶ Conceptually, this means moving away from defining OS through appeals to general principles and context-independent ideals of best practice, focusing instead on a procedural approach to OS as the ensemble of practices that facilitate critical scrutiny and re-use of research components and results, including of the demarcation criteria used by researchers to

⁵ This raises an issue for Chang’s framing: while convergence on a problem agenda or set of goals is often an important component of demarcation strategies within a system of practice, it may not be a necessary requirement since other factors (e.g. agreement on specific methods of evaluation) can also ground demarcation strategies and ensure the coherence of epistemic activities. Discussing this issue falls outside the scope of this paper and I shall come back to it elsewhere.

⁶ For a critique of OS as supporting conservatism, private interests and inequity, see Mirowski (2018).

adjudicate who constitutes a relevant beneficiary of and/or contributor (Levin and Leonelli 2017). Methodologically, this involves improving researchers' capacity to choose and develop systems of practice (and related demarcation strategies) that are well-suited to their targets and goals - which in turn requires transdisciplinary exchanges that help to identify appropriate and responsible manners of OS implementation, as well as provisions for research situations where digital tools are not immediately available or even relevant. Institutionally, OS needs to challenge existing systems for academic reward and publishing, and foster venues and tools to critically evaluate whether and how currently dominant repertoires serve existing and future epistemic goals. Last but not least, the transition to OS provides philosophers with an opportunity to further unpack the situatedness of knowledge production and ecological understandings of scientific reasoning long advocated by feminist epistemologists (Code 2006). The push to implement OS demands a systematic account of the implications of epistemic diversity in its various forms, as well as the role played by all components of research – including overlooked ones such as data, samples and software – towards probing the credibility of scientific results.

References

Ankeny, Rachel A and Sabina Leonelli. 2016. Repertoires: A Post-Kuhnian Perspective on Scientific Change and Collaborative Research. *Studies in the History and the Philosophy of Science: Part A* 60: 18-28.

Bezuidenhout, Louise, Sabina Leonelli, Ann Kelly and Brian Rappert. 2017. Beyond the Digital Divide: Towards a Situated Approach to Open Data. *Science and Public Policy* 44(4): 464-475

Boulton, Geoffrey et al. 2012. *Science as an Open Enterprise*. 02/12. London: The Royal Society Science Policy Centre.

Burgelman, Jean-Claude et al. 2019. Open Science, Open Data, and Open Scholarship: European Policies to Make Science Fit for the Twenty-First Century. *Frontiers in Big Data* 2, 43.

Chang, Hasok. 2013. *Water is not H₂O: Evidence, Realism and Pluralism*. Springer.

Chapman, Robert and Alison Wylie 2016. *Evidential Reasoning in Archaeology*. Bloomsbury.

Code, Lorraine. 2006. *The Politics of Epistemic Location*. Oxford University Press.

Elliott, Kevin and David B. Resnik. 2019. Making open science work for science and society. *Environmental Health Perspectives* 127:075002.

European Commission. 2015. *Open Innovation, Open Science, Open to the World*.

Luxembourg: Publications Office of the European Union.

Fecher Benedikt and Sarah Friesike. 2014. Open Science: One Term, Five Schools of Thought. In Bartling and Friesike (eds.), *Opening Science. The Evolving Guide on How the Internet is Changing Research, Collaboration and Scholarly Publishing*. Springer.

Feest, Uljana. 2017. Phenomena and Objects of Research in the Cognitive and Behavioral Sciences. *Philosophy of Science* 84, 1165-1176.

----- 2019. Why Replication Is Overrated. *Philosophy of Science* 86:5, 895-905.

Güttinger, Stephan. 2020. The Limits of Replicability. *European Journal for Philosophy of Science* 10:10.

Knorr-Cetina, Karen. 1999. *Epistemic Cultures: How Science Makes Knowledge*. Harvard University Press.

Kellert SH, Longino Helen E., and Waters CK (2006, eds) *Scientific Pluralism*. University of Minnesota Press.

Leonelli, S. (2021) Data Science in Times of Pan(dem)ic. *Harvard Data Science Review* 3(1) <https://doi.org/10.1162/99608f92.fbb1bdd6>

Leonelli, Sabina. 2018a. Global Data Quality Assessment and the Situated Nature of “Best” Research Practices in Biology. *Data Science*. 16(32): 1-11.

----- 2018b. Re-Thinking Reproducibility as a Criterion for Research Quality. *Research in the History of Economic Thought and Methodology*. Volume 36B, 129-146.

Krige, John and Sabina Leonelli. 2021. Mobilizing the Translational History of Knowledge Flows: COVID-19 and the Politics of Knowledge at the Borders. *History and Technology*.
<https://doi.org/10.1080/07341512.2021.1890524>

Levin, Nadine and Sabina Leonelli. 2017. How Does One “Open” Science? Questions of Value in Biological Research. *Science, Technology and Human Values* 42 (2): 280-305.

Levin, Nadine et al. 2016. How Do Scientists Understand Openness? Exploring the Relationship between Open Science Policies and Research Practice. *Bulletin for Science and Technology Studies* 36(2): 128-141.

Longino, Helen E. (2003) *The Fate of Knowledge*. Princeton University Press.

Maxson Jones, Katherine, Rachel A. Ankeny and Robert Cook-Deegan. 2018. The Bermuda Triangle: The Pragmatics, Policies, and Principles for Data Sharing in the History of the Human Genome Project. *J Hist Biol*. 51(4):693-805.

Mirowski, Philip. 2018. The future of (open) science. *Social Studies of Science* 48(2):171-203.

Mitchell, Sandra (2003) *Biological Complexity and Integrative Pluralism*. Cambridge University Press.

McLeod, Miles and Nancy Nersessian. 2013. The creative industry of integrative systems biology. *Mind & Society* 12: 35-48.

Open Letter (2021) Support data sharing for COVID-19.

<https://www.covid19dataportal.org/support-data-sharing-covid19>

Open Science Policy Platform. 2018. *OSPP-REC: Recommendations of the Open Science Policy Platform*.

Radder Hans 1996, *In and About the World: Philosophical Studies of Science and Technology*. New York State University Press.

Romero, Felipe. 2019. Philosophy of Science and the Replicability Crisis. *Philosophical Compass* 14: e12633.

Strasser, Bruno. 2019. *Collecting Experiments: Making Big Data Biology*. Chicago University Press.

Acknowledgments: This research received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreements No. 335925 and 101001145). This paper reflects only the author's view and that

the Commission / Agency is not responsible for any use that may be made of the information it contains. I am also grateful to the fantastic research support and impeccable hospitality of the Wissenschaftskolleg zu Berlin, without which I would not have managed to complete this draft manuscript in time for submission to PSA proceedings.