“Reproducibility and Replication in Science” Report Recommendations

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“Reproducibility and Replication in Science”

- The 2017 “American Innovation and Competitiveness Act” provided funding for several agencies including NSF, and contained a section called ‘Research Reproducibility and Replication’ allocating funding for a report that assesses “research and data reproducibility and replicability issues in interdisciplinary research” and makes “recommendations for improving rigor and transparency in scientific research.”

- National Academies of Science, Engineering, and Medicine convened a committee to produce a consensus report, published in 2019.

- All committee meetings and talks available on NASEM website https://www.nationalacademies.org/our-work/reproducibility-and-replicability-in-science (see Past Events)

- 5 commissioned white papers.

Report and white papers available at https://www.nap.edu/catalog/25303/reproducibility-and-replicability-in-science

Report Distinguishes Reproducibility & Replicability

The terms, “reproducibility” and “replicability” have different meanings and uses across science and engineering, which has led to confusion in collectively understanding problems in reproducibility and replicability. The committee adopted specific definitions for the purpose of this report to clearly differentiate between the terms, which are otherwise interchangeable in everyday discourse.

Reproducibility is obtaining **consistent results using the same input data, computational steps, methods, and code, and conditions of analysis**. This definition is synonymous with “computational reproducibility,” and the terms are used interchangeably in this report.

Replicability is obtaining **consistent results across studies aimed at answering the same scientific question**, each of which has obtained its own data. Two studies may be considered to have replicated if they obtain consistent results given the level of uncertainty inherent in the system under study.

Priority Recommendations

See https://docs.google.com/document/d/1qBvUODwH3MbbbHYYLakbpAoj2-D5v9iF3VA7mZqRgL8/edit?usp=sharing

Recommendation 4-1

To help ensure the reproducibility of computational results, *researchers should convey clear, specific, and complete information about any computational methods and data products that support their published results* in order to enable other researchers to repeat the analysis, unless such information is restricted by non-public data policies. That information should include the data, study methods, and computational environment:

- *the input data* used in the study either in extension (e.g., a text file or a binary) or in intension (e.g., a script to generate the data), as well as intermediate results and output data for steps that are nondeterministic and cannot be reproduced in principle;

- *a detailed description of the study methods (ideally in executable form)* together with its computational steps and associated parameters; and

- *information about the computational environment* where the study was originally executed, such as operating system, hardware architecture, and library dependencies (which are relationships described in and managed by a software dependency manager tool to mitigate problems that occur when installed software packages have dependencies on specific versions of other software packages).

Recommendation 6-6

Many stakeholders have a role to play in improving computational reproducibility, including educational institutions, professional societies, researchers, and funders.

- Educational institutions should educate and train students and faculty about computational methods and tools to improve the quality of data and code and to produce reproducible research.

- ***Professional societies should take responsibility for educating the public and their professional members about the importance and limitations of computational research. Societies have an important role in educating the public about the evolving nature of science and the tools and methods that are used.***

- Researchers should collaborate with expert colleagues when their education and training are not adequate to meet the computational requirements of their research.

- In line with its priority for "harnessing the data revolution," the National Science Foundation (and other funders) should consider funding of activities to promote computational reproducibility.

Recommendation 6-4

Journals should consider ways to ensure computational reproducibility for publications that make claims based on computations, to the extent ethically and legally possible. Although ensuring such reproducibility prior to publication presents technological and practical challenges for researchers and journals, new tools might make this goal more realistic. Journals should make every reasonable effort to use these tools, make clear and enforce their transparency requirements, and increase the reproducibility of their published articles.

Recommendation 6-7

Journals and scientific societies requesting submissions for conferences should disclose their policies relevant to achieving reproducibility and replicability. The strength of the claims made in a journal article or conference submission should reflect the reproducibility and replicability standards to which an article is held, with stronger claims reserved for higher expected levels of reproducibility and replicability. Journals and conference organizers are encouraged to:

- **set and implement desired standards** of reproducibility and replicability and make this one of their priorities, such as deciding which level they wish to achieve for each Transparency and Openness Promotion guideline and working towards that goal;

- **adopt policies** to reduce the likelihood of non-replicability, such as considering incentives or requirements for research materials transparency, design, and analysis plan transparency, enhanced review of statistical methods, study or analysis plan preregistration, and replication studies; and

- **require as a review criterion** that all research reports include a thoughtful discussion of the uncertainty in measurements and conclusions.

Recommendation 6-8

Many considerations enter into decisions about what types of scientific studies to fund, including striking a balance between exploratory and confirmatory research. If private or public funders choose to invest in initiatives on reproducibility and replication, two areas may benefit from additional funding:

- *education and training initiatives* to ensure that researchers have the knowledge, skills, and tools needed to conduct research in ways that adhere to the highest scientific standards; that describe methods clearly, specifically, and completely; and that express accurately and appropriately the uncertainty involved in the research; and

- ***reviews of published work*, such as testing the reproducibility of published research, conducting rigorous replication studies, and publishing sound critical commentaries.**

Other Recommendations

See https://docs.google.com/document/d/1qBvUODwH3MbbbHYYLakbpAoj2-D5v9iF3VA7mZqRgL8/edit?usp=sharing

Recommendation 6-3

Funding agencies and organizations should consider investing in research and development of open-source, usable tools and infrastructure that support reproducibility for a broad range of studies across different domains in a seamless fashion. Concurrently, investments would be helpful in outreach to inform and train researchers on best practices and how to use these tools.

Recommendation 6-5

In order to facilitate the transparent sharing and availability of digital artifacts, such as data and code, for its studies, the National Science Foundation (NSF) should:

- **Develop a set of *criteria for trusted open repositories* to be used by the scientific community for objects of the scholarly record.**

- Seek to *harmonize with other funding agencies* the repository criteria and data-management plans for scholarly objects.

- *Endorse or consider creating code and data repositories for long-term archiving and preservation of digital artifacts that support claims made in the scholarly record based on NSF-funded research*. These archives could be based at the institutional level or be part of, and harmonized with, the NSF-funded Public Access Repository.

- *Consider extending NSF's current data-management plan to include other digital artifacts, such as software.*

- Work with communities reliant on non-public data or code to *develop alternative mechanisms* for demonstrating reproducibility. Through these repository criteria, NSF would enable discoverability and standards for digital scholarly objects and discourage an undue proliferation of repositories, perhaps through endorsing or providing one go-to website that could access NSF-approved repositories.

Recommendation 6-9

Funders should require a thoughtful discussion in grant applications of how uncertainties will be evaluated, along with any relevant issues regarding replicability and computational reproducibility. Funders should introduce review of reproducibility and replicability guidelines and activities into their merit-review criteria, as a low-cost way to enhance both.

Recommendation 6-10

When funders, researchers, and other stakeholders are considering whether and where to direct resources for replication studies, they should consider the following criteria:

- The scientific results are important for individual decision-making or for policy decisions.
- The results have the potential to make a large contribution to basic scientific knowledge.
- The original result is particularly surprising, that is, it is unexpected in light of previous evidence and knowledge.
- There is controversy about the topic.
- There was potential bias in the original investigation, due, for example, to the source of funding.
- There was a weakness or flaw in the design, methods, or analysis of the original study.
- The cost of a replication is offset by the potential value in reaffirming the original results.
- Future expensive and important studies will build on the original scientific results.

Recommendation 7-1 & 7-2

RECOMMENDATION 7-1: **Scientists should take care to avoid overstating the implications of their research** and also exercise caution in their review of press releases, especially when the results bear directly on matters of keen public interest and possible action.

RECOMMENDATION 7-2: Journalists should report on scientific results with as much context and nuance as the medium allows. In covering issues related to replicability and reproducibility, journalists should help their audiences understand the differences between non-reproducibility and non- replicability due to fraudulent conduct of science and instances in which the failure to reproduce or replicate may be due to evolving best practices in methods or inherent uncertainty in science. Particular care in reporting on scientific results is warranted when:

- the scientific system under study is complex and with limited control over alternative explanations or confounding influences;

- a result is particularly surprising or at odds with existing bodies of research;

- the study deals with an emerging area of science that is characterized by significant disagreement or contradictory results within the scientific community; and

- research involves potential conflicts of interest, such as work funded by advocacy groups, affected industry, or others with a stake in the outcomes.

Recommendation 7-3

Anyone making personal or policy decisions based on scientific evidence should be wary of making a serious decision based on the results, no matter how promising, of a single study. Similarly, no one should take a new, single contrary study as refutation of scientific conclusions supported by multiple lines of previous evidence.

For recommendations see https://docs.google.com/document/d/1qBvUODwH3MbbbHYYLakbpAoj2-D5v9iF3VA7mZqRgL8/edit?usp=sharing

For NASEM Report see https://www.nap.edu/catalog/25303/reproducibility-and-replicability-in-science

Legal Issues in Software

Intellectual property is associated with software (and all digital scholarly objects) e.g the U.S. Constitution and subsequent Acts:

"*To promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries*." (U.S. Const. art. I, §8, cl. 8)

Copyright

- Original expression of ideas falls under copyright by default (papers, code, figures, tables..)
- Copyright secures exclusive rights vested in the author to:
  - reproduce the work
  - prepare derivative works based upon the original
- limited time: generally life of the author +70 years
- Exceptions and Limitations: e.g. Fair Use.

Patents

Patentable subject matter: "*new and useful process, machine, manufacture, or composition of matter, or any new and useful improvement thereof*" (35 U.S.C. §101) that is

1. *Novel*, in at least one aspect,
2. *Non-obvious*,
3. *Useful*.

USPTO Final Computer Related Examination Guidelines (1996) "A practical application of a computer-related invention is statutory subject matter. This requirement can be discerned from the variously phrased prohibitions against the patenting of abstract ideas, laws of nature or natural phenomena" (see e.g. Bilski v. Kappos, 561 U.S. 593 (2010)).

Bayh-Dole Act (1980)

- Promote the transfer of academic discoveries for commercial development, via licensing of patents (ie. Technology Transfer Offices), and harmonize federal funding agency grant intellectual property regs.

- Bayh-Dole gave federal agency grantees and contractors title to government-funded inventions and charged them with using the patent system to aid disclosure and commercialization of the inventions.

- Hence, institutions such as universities charged with utilizing the patent system for technology transfer.

Legal Issues in Data

- In the US raw facts are not copyrightable, but the original “selection and arrangement” of these facts is copyrightable. (Feist Publns Inc. v. Rural Tel. Serv. Co., 499 U.S. 340 (1991)).

- Copyright adheres to raw facts in Europe.

- the possibility of a residual copyright in data (attribution licensing or public domain certification).

- Legal mismatch: What constitutes a “raw” fact anyway?

The Reproducible Research Standard

The *Reproducible Research Standard* (*RRS*) (Stodden, 2009)

A suite of license recommendations for computational science:

- Release media components (text, figures) under **CC BY**,
- Release code components under **MIT License** or similar,
- Release data to public domain (**CC0**) or attach attribution license.

➡ *Remove copyright's barrier to reproducible research and,*

➡ *Realign the IP framework with longstanding scientific norms.*