The National Academies of
SCIENCES · ENGINEERING · MEDICINE

Findings, Conclusions & Recommendations from Two US NASEM Reports

6^{th} WCRI Hong Kong

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Outline

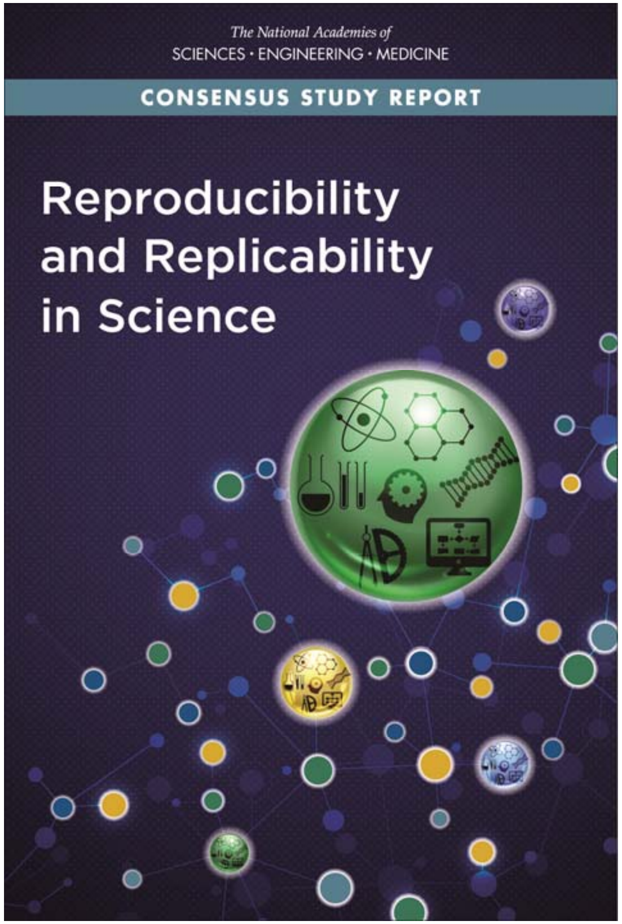
- About NASEM
- 1st Report: Reproducibility and Replicability in Science
- 2nd Report: Open Science by Design: Realizing a Vision for 21st Century Research
- Implications and What's Next?

National Academies of Sciences, Engineering, and Medicine

- Private, non-profit, self-selecting membership organizations of eminent scientists, engineers, medical professionals
- Congressional charter to advise the Federal government
- Organization: 6 major divisions, boards/standing committees, ad hoc committees
- Operating modes: Consensus studies, convening activities (workshops, roundtables), operational programs (fellowships, etc.)

1st Report: Reproducibility and Replicability in Science

- Mandated by Congress, responding to debates of recent years
- Sponsored by the National Science Foundation and the Alfred P. Sloan Foundation
- Led by Division on Behavioral and Social Sciences and Education with participation from several other NASEM divisions
- Released May 2019



Committee on Reproducibility and Replicability in Science

Harvey V. Fineberg, Chair, Gordon and Betty Moore Foundation

David B. Allison, Indiana University
Lorena A. Barba, The George Washington University
Dianne Chong, Boeing Research and Technology (Retired)
David L. Donoho,* Stanford University
Juliana Freire, New York University
Gerald Gabrielse, Northwestern University
Constantine Gatsonis, Brown University

*Resigned from committee July 2018

Edward (Ned) Hall, Harvard University
Thomas H. Jordan, University of Southern California
Dietram A. Scheufele, University of Wisconsin-Madison
Victoria Stodden, University of Illinois at Urbana-Champaign
Simine Vazire,** University of California, Davis
Timothy Wilson, University of Virginia
Wendy Wood, University of Southern California

**Resigned from committee October 2018

Committee's Charge

– Define reproducibility and replicability accounting for the diversity of fields in science and engineering.*

– Examine the extent of non-reproducibility and non-replicability.

– Review current activities to improve reproducibility and replicability (R&R).

– Determine if the lack of replicability and reproducibility impacts the overall health of science and engineering as well as the public's perception of these fields.

*"the committee may consider what can be learned from…efforts to improve reproducibility and replication in biomedical and clinical research…(but)…the recommendations… will focus on…(fields/disciplines)…that fall within the scope of the National Science Foundation."

Emphasis on Definitions

"One big problem keeps coming up among those seeking to tackle the issue: different groups are using terminologies in utter contradiction with each other."

Lorena Barba, 2018

Recommended Definitions

Reproducibility is obtaining consistent results using the same input data, computational steps, methods, and code, and conditions of analysis.

Replicability is obtaining consistent results across studies aimed at answering the same scientific question, each of which has obtained its own data.

Reproducibility

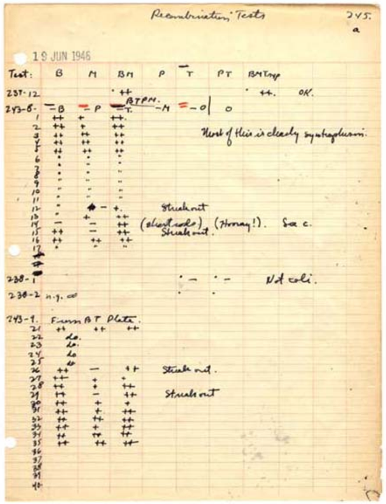
Context: Pervasive use of computation across disciplines; growing adoption of reproducible science.

Extent: No universal standards for assessment; evidence base incomplete; a number of systematic efforts to reproduce computational results have failed in more than half the attempts.

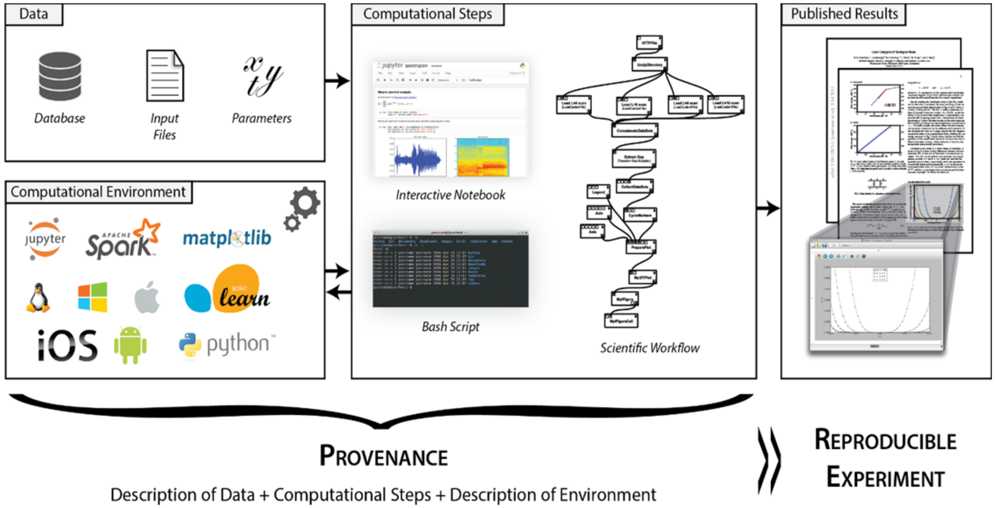
Causes: Inadequate record keeping, Non-transparent reporting, Obsolescence of the digital artifacts, Flawed attempts to reproduce other's results, Barriers in culture

Reproducibility: Challenges

- Experiments are complex and involve many steps: need to systematically capture and report detailed provenance: data, code, computational environment
- Full reproducibility is not always possible: proprietary and non-public data, code and hardware
- Transparency contributes to the confidence in results



DNA recombination By Lederberg



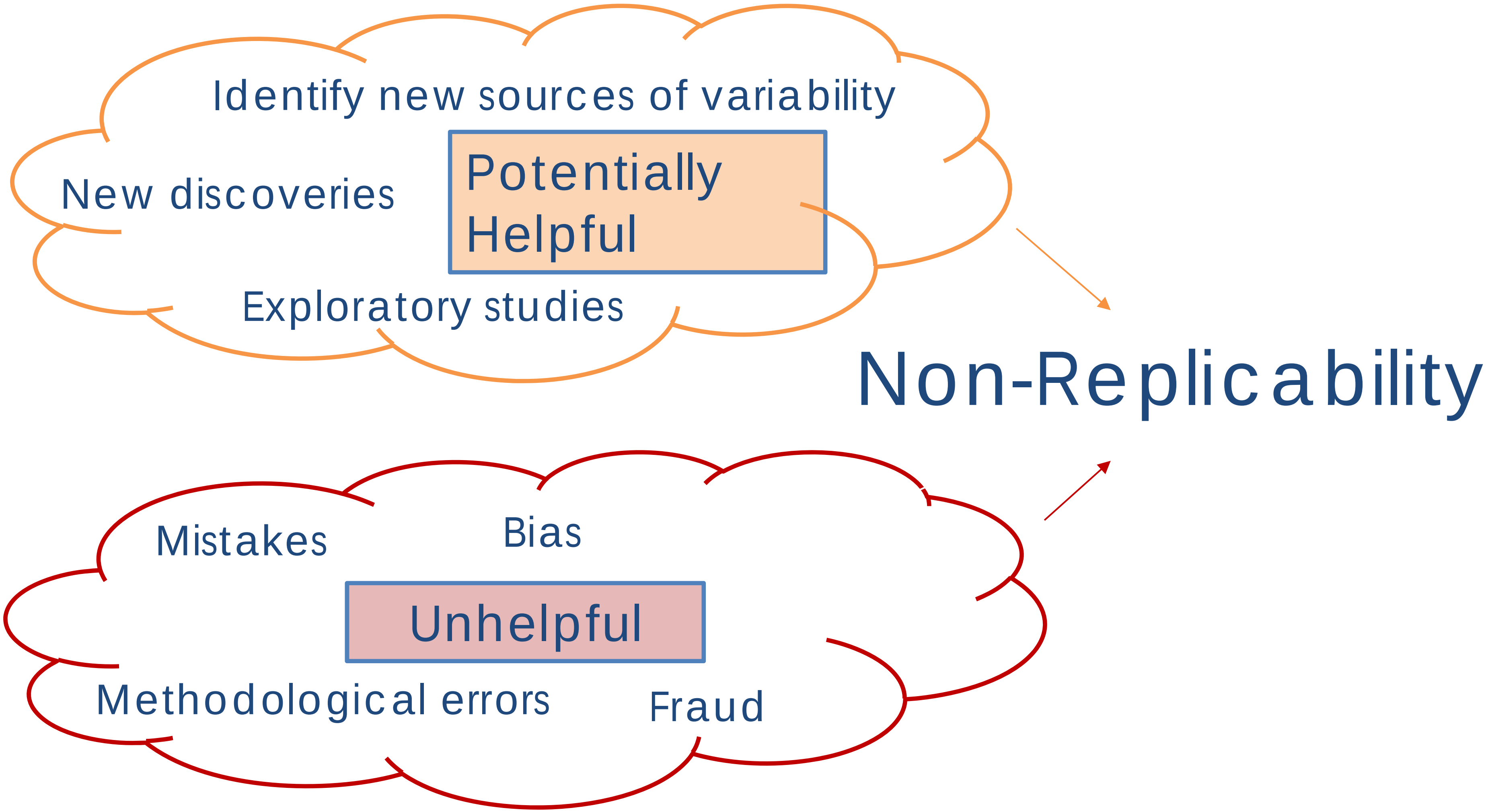
Replicability Is Nuanced

- Bitwise reproducibility may be possible, but exact replicability usually isn't
- Some studies not amenable to direct replication (e.g. ephemeral phenomena)
- Many *de facto* replications go unreported as such
- Non-replicability in any discipline is related to key attributes of the system under study (e.g. Complexity, Intrinsic variability, Controllability, Precision of measurement)
- Clear reporting of uncertainty + clear, specific and complete reporting of methods necessary
- Criteria for replication should take account of both the central tendency and variability in results

When should replication studies be performed?

- Results important for policy, decision making, and science
- Results unexpected/controversial or involve potential bias
- Recognized weaknesses in the original study
- Costs offset by potential benefits for science and society

Sources of Non-Replicability: "Potentially Helpful" and "Unhelpful" to the Advancement of Science



Statistical Inference and Replicability

- Outsized role in the replicability debate
- Misunderstanding and misuse of *p*-values
  - Erroneous calculations
  - Confusion about meaning
  - Excess reliance on arbitrary thresholds of "statistical significance"
  - Bias in reporting
- Meta-analysis and research synthesis

Not a crisis? But no room for complacency

- Improvements are needed.
- Reproducibility is important but not currently easy to attain.
- Aspects of replicability of individual studies are a serious concern.

Neither are the main or most effective way to ensure reliability of scientific knowledge.

Key Recommendations to Improve R&R

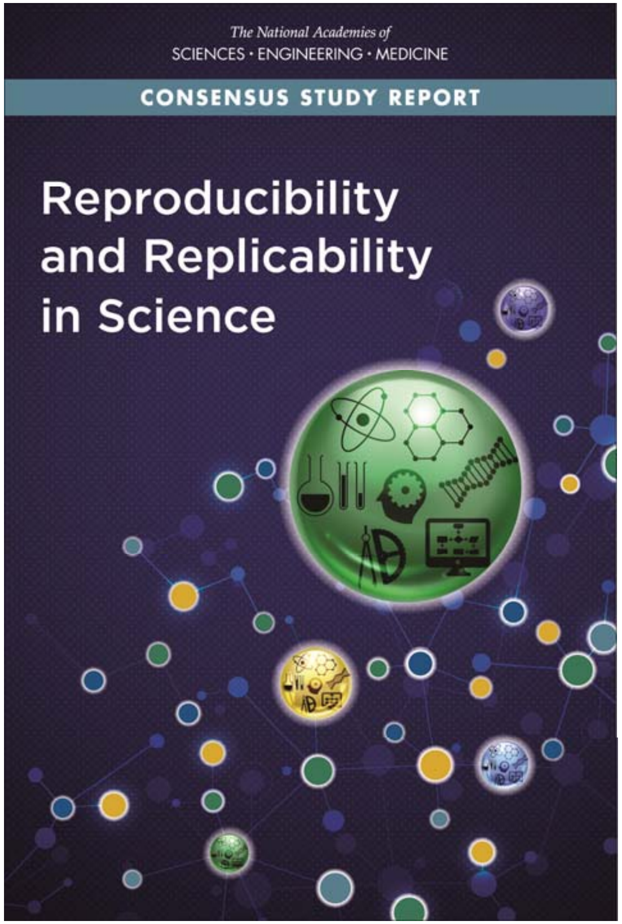
- **Researchers**: include a clear, specific, and complete description of how the reported results were reached,
- **Funding agencies/organizations**: consider investing in open-source, usable tools, infrastructure, and related training that support reproducibility and replicability,
- **Journals**: consider ways to ensure computational reproducibility to the extent possible
- **Professional/Scientific Societies**: Educate members and the public; include discussion of uncertainty in measurements/conclusions
- **Policy Makers**: Seek convergent evidence when contemplating important action based on a single study
- **NSF**: Facilitate transparent sharing and availability of digital artifacts, such as data and code, for NSF-funded studies (e.g. repositories). Require evaluation of uncertainties in grant applications and incorporate assessment of R&R in merit review

R&R and Confidence in Science

Scientists: avoid overstating the implications of research, exercised also in review of press releases, especially when the results bear directly on matters of keen public interest and possible action.

Journalists: report on scientific results with as much context and nuance as the medium allows; help 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.

Additional Information



- Free pdf of the report available
- Overview video
- Report highlights
- “10 things to know” infographic

www.nationalacademies.org/ReproducibilityinScience

2nd Report: Open Science by Design: Realizing a Vision for 21st Century Research

- Consensus study undertaken by the Board on Research Data and Information
- 10-member committee chaired by Alexa McCray, PhD, of Harvard Medical School
- Released in July 2018
- **Funder:** The Laura & John Arnold Foundation

Committee on Toward an Open Science Enterprise

- **Alexa T. McCray (NAM)** (Chair), Harvard Medical School
- **Francine Berman**, Rensselaer Polytechnic Institute
- **Michael Carroll**, American University Washington College of Law
- **Donna Ginther**, University of Kansas
- **Robert Miller**, LYRASIS
- **Peter Schiffer**, Yale University
- **Edward Seidel**, University of Illinois at Urbana-Champaign
- **Alex Szalay**, The Johns Hopkins University
- **Lisa Tauxe (NAS)**, University of California, San Diego
- **Heng Xu**, The Pennsylvania State University

Open Science by Design: Realizing a Vision of 21st Century Research

Committee's Focus

"Identify and address the challenges of broadening access to…scientific research" and develop recommendations aimed at moving "toward open science as the default for scientific research results"

What is Open Science?

Open science aims to ensure the open availability and usability of scholarly publications, the data that result from scholarly research, and the methodologies, including code or algorithms, that were used to generate those data.

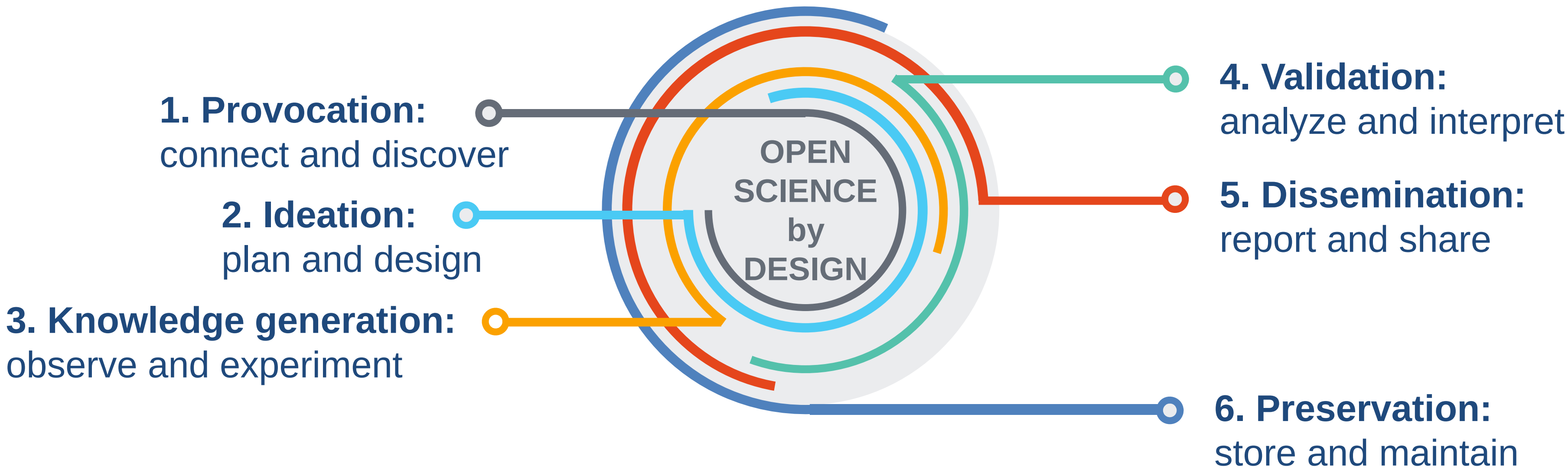
Benefits and Motivations of Open Science

- Rigor and reliability
- Ability to address new questions
- Faster and more inclusive dissemination of knowledge
- Broader participation in research
- Effective use of resources
- Improved performance of research tasks
- Open publication for public benefit

Barriers and Limits to Achieving Open Science

- Costs and insufficient infrastructure
- Structure of scholarly communications
- Lack of supportive culture, incentives and training
- Privacy, security, and proprietary barriers to sharing
- Disciplinary differences

Open Science by Design



A set of principles and practices that empowers the researcher to conduct research openly and transparently throughout every phase of the research process.

Open Science by Design

- **Provocation:** explore/mine open research resources and use open tools to network with colleagues.
- **Ideation:** develop and revise research plans and prepare to share research results and tools under FAIR (**F**indable, **A**ccessible, **I**nteroperable, **R**eusable) principles.
- **Knowledge generation:** collect data, conduct research using tools compatible with open sharing, and use automated workflow tools to ensure accessibility of research outputs.
- **Validation:** prepare data and tools for reproducibility and reuse and participate in replication studies.
- **Dissemination:** use appropriate licenses for sharing research outputs and report all results and supporting information, including data and code.
- **Preservation:** deposit research outputs in FAIR archives and ensure long-term access to research results.

Building a Supportive Culture

- **Finding:** Continued effort by stakeholders, working internationally and across disciplinary boundaries, is needed to **change evaluation practices and introduce other incentives so that the cultural environment of research better supports and rewards open practices.**

  - **Recommendation One:** Research institutions should work to create a culture that actively supports Open Science by Design by **better rewarding and supporting researchers engaged in open science practices.** Research funders should provide explicit and consistent support for practices and approaches that facilitate this shift in culture and incentives.

Training for Open Science by Design

- **Finding:** There is little formal training and education in the principles and practices of open science. The emergence of data science as a recognized interdisciplinary field has highlighted the need for new educational content and approaches related to data.

  - **Recommendation Two:** Research institutions and professional societies should train students and other researchers to implement open science practices effectively and should support the development of educational programs that foster Open Science by Design.

Ensuring Long-Term Preservation and Stewardship

- **Finding:** Developing and sustaining the infrastructure required for long-term stewardship of research products will present a continuing challenge.

  - **Recommendation Three:** Research funders and research institutions should develop the policies and procedures to identify the data, code, specimens, and other research products that should be preserved for long-term public availability, and they should **provide the resources necessary for the long-term preservation and stewardship of those research products.**

Facilitating Data Discovery, Reuse, and Reproducibility

- **Finding:** As progress toward opens science by design continues, it is important that the community adhere to the ultimate goal of achieving the availability of research products under open principles.

  - **Recommendation Four:** Funders that support the development of research archives should **work to ensure that these are designed and implemented according to the FAIR data principles.** Researchers should seek to ensure that their research products are made available according to the FAIR principles and state with specificity any exceptions based on legal and ethical considerations.

Developing New Approaches to Fostering Open Science by Design

- **Finding:** Public and private funders have made significant contributions to fostering open science to this point. They should continue to **support initiatives that accelerate progress, and evaluate and revise their policies as needed.**

    - **Recommendation Five:** The research community should work together to realize Open Science by Design to advance science and help science better serve the needs of society.

An Inflection Point?

- A new generation of information technology tools and services holds the potential of further revolutionizing scientific practice
- Public and private research funders have introduced mandates and support systems to ensure that the results of the research they sponsor are open (e.g. Plan S)
- Publishers are adopting open frameworks and strengthening requirements to ensure that the data and methods underlying articles are available

Implications of these reports

- Both reports emphasize the strong connection between openness/transparency and better/more reliable/more trusted science
- Both reports recognize that persistent, multi-stakeholder efforts are needed to move the research enterprise forward in adapting to technology, globalization, and other fundamental changes
- Need top-down policies (mandates, requirements, funding) and community leadership (standards, infrastructure solutions)
- New ecosystem needs to work for researchers—address incentives, costs, ease of use, and demonstrate the scientific benefits of open and R&R-friendly practices

Impacts and Next Steps

- Continued efforts to disseminate the reports—to this point Open Science by Design has about 7,700 full-text downloads and Reproducibility and Replicability in Science has about 4,300
- September 24 symposium on R&R
- New Roundtable on Aligning Incentives for Open Science and new study on scientific workflows

Thank You!

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