NSF Dear Colleague Letter - Open Science Hardware

[Call](#call)

[White Paper](#white-paper)

## Call

Link to call: https://www.nsf.gov/pubs/2017/nsf17131/nsf17131.jsp

Dear Colleague:

This Dear Colleague Letter (DCL) invites individuals or groups of individuals from the U.S. research community to submit White Papers on topics in science, engineering, and/or STEM education that are ripe for international network-to-network collaboration. Topics should hold the potential to accelerate discovery and advance research outcomes.

The National Science Foundation (NSF) Office of International Science and Engineering (OISE) will use the white papers to inform OISE planning, including the potential need for a future program or program emphasis.

The deadline for white paper submission is: 11:59 p.m. Eastern Time November 30, 2017.

### BACKGROUND

The Office of International Science and Engineering supports U.S. participation in strategic international research collaborations. Increasing investment in science, engineering, and STEM education by other nations creates new communities of research excellence. OISE seeks input from the U.S. research community to identify respective networks in the U.S. and abroad that could be better connected to leverage expertise, data, facilities, and/or other resources to stimulate critical research advances through networks of networks.

Research areas with sufficient maturity to have a nascent, but not well-established, network of researchers in the U.S. and abroad are of particular interest. Interdisciplinary research ideas are encouraged, though ideas are welcome in any area funded by NSF where strategic bridges between U.S. and international networks would create mutual benefit. There should be potential to link multiple networks, leading to a network of networks. In keeping with NSF's experience with research coordination networks, for the purposes of this call networks will involve groups of investigators who communicate and coordinate their research and educational activities across organizational and international boundaries. The properties of networks include multi-institutional collaborations involving diverse teams of investigators focused on community-identified questions or needs. Thus, the envisioned networks of networks should go beyond existing or emerging concentrations of expertise and should strengthen community linkages across boundaries. Topic areas may span the range of science, engineering, and STEM education fields. Activities should be open to a wide range of U.S. institutions in the topic area. The size and participants of the network of networks will vary depending on the community-identified question and current connectivity between U.S. and foreign networks. Responses should address research areas where enhanced international cooperation between U.S. and foreign networks would strengthen the U.S. research community and offer mutual benefit to accelerate discoveries.

Submit Your White Paper at:
https://www.surveymonkey.com/r/OISE-ACCELNET_Topic_Ideas_2018.

NSF invites both individuals and groups of individuals from U.S. institutions to submit white papers. International researchers are welcome to be part of the white paper team, but the submission must be made by U.S.-based researchers.

Submit your ideas by 11:59 p.m. Eastern Time on November 30, 2017. Include the following:

- Name, affiliation, and valid email contact information for submitter(s).
- List up to three terms that represent keywords of your submission (This may be made public in aggregate with other submissions).
- What current or emerging research areas would benefit from increased cooperation between networks of researchers in the U.S. and networks in one or more countries outside the U.S.?
- What is the value added of international network-to-network collaboration for the U.S. research community in the research area(s)?
- What other relevant aspects should NSF consider to strengthen international research networks in the research area(s)?

**White papers are limited to 2,000 words maximum.**

**This DCL is not a call for research proposals. Rather, it is an information-gathering effort to inform OISE of the potential need for a future program or program emphasis.** No funding is associated with this call for white papers. Responses to this DCL do not constitute any commitment on behalf of the submitters or their institutions to submit a proposal or carry out an international network-to-network project.

After the submission period ends, and the white paper information is analyzed, NSF will announce the high-level insights drawn from the analysis of keyword terms on the OISE website.

Inquiries may be directed to oise-accelnet@nsf.gov.

# Accelerating science and improving equitable access to hands-on STEM education through open science hardware

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Andre Maia Chagas, University of Tübingen, Germany
Fernán Federici, Universidad Católica de Chile, Chile.

**List up to three terms that represent keywords of your submission**

Open Hardware, scientific tools, open science

## What current or emerging research areas would benefit from increased cooperation between networks of researchers in the U.S. and networks in one or more countries outside the U.S.? (750 words)

There is an opportunity to radically reduce the cost of scientific instruments while improving the quality and impact of scientific research by supporting Open Science Hardware (OScH)[1] development on an international scale. We argue for supporting a multidisciplinary research network of scholars, students, and practitioners who are contributing to OScH research, development, and deployment all over the world. This network-of-networks approach would span the disciplines of hardware engineering, design, STEM education, the natural sciences, and science and technology studies (STS) to name a few. The OScH community is nascent both in the U.S. and around the world but enhanced international cooperation at this point in time would catalyze its potential to accelerate research, enable a broader audience to access the necessary tools for experimental science and increase equitable access to high-quality, hands-on STEM education for the mutual benefit of U.S. researchers and international networks.

The motivation behind this research area is that lack of access to appropriate hardware reduces opportunities for people to engage with science and restricts the creativity and reproducibility of experimental designs. A growing number of scientific communities in the U.S. and globally are therefore developing OScH for both research[2] and STEM education as an alternative to proprietary 'black box' instrumentation, which cannot be fully inspected or customized and can be unreasonably difficult and expensive to obtain and maintain. OScH on the other hand can be obtained, assembled, used, studied, modified, shared, and sold by anyone.[3] It is typically shared using open licenses and by providing the bill of materials, schematics, assembly instructions, and procedures needed to fabricate a digital replica of the original. Much of this activity builds on increasingly connected maker communities[4], leveraging broader access to digital manufacturing tools such as 3-D printers and open source electronics platforms like Arduino, which reduce the necessary investments in time and funding required for prototyping solutions and replicating existing designs.

By harnessing this scalable open source approach, a network of networks would apply federal funding just once on the development of scientific equipment, and return this investment by replicating the open source designs for research and education at only the costs of the materials used. NSF also has the opportunity to leverage its past investments[5] in maker education, expanding the resources available for maker entrepreneurs, and in fostering the development of advanced manufacturing in the U.S. By creating a network of networks with a specific focus on OScH, existing expertise, information and facilities can be shared for mutual benefit. Moreover, cooperation and collaboration are inherent to open hardware development and underpin its iterative improvement, so technical advances in the area will be accelerated by timely and increased investment in network coordination.

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[1] Pearce J. M. (2014) *Open-Source Lab: How to Build Your Own Hardware and Reduce Research Costs*.
New York: Elsevier.
[2] Pearce, J. M. (2012). Building research equipment with free, open-source hardware. *Science*, *337*(6100), 1303-1304.
[3] Gibney, E. (2016). 'Open-hardware' pioneers push for low-cost lab kit: conference aims to raise awareness of shared resources for building lab equipment. *Nature*, *531*(7593), 147-149.
[4] Walter-Herrmann, J., & Büching, C. (Eds.). (2014). *FabLab: Of machines, makers and inventors*. Verlag.
[5] https://www.nsf.gov/news/news_summ.jsp?cntn_id=138994

Instrumentation is a central facet of both professional and amateur participation in science, and there are several research areas that would benefit from a network-to-network approach in addition to those benefiting from accelerated technical progress. There will be direct impact on a number of existing fields that already integrate open science hardware—most notably the natural sciences that rely on citizen-driven data collection; engineering fields that are developing novel low-cost fabrication techniques (e.g., 3D printing); social science inquiries that examine the societal, ethical, and philosophical aspects of democratic science practice; and STEM pedagogy approaches that are incorporating low-cost hardware into classroom and informal learning activities (such as those supported by the NSF Advancing Informal STEM Learning track). In addition, the network-in-networks approach would promote OSH as a new field of study in itself that integrates methodological perspectives from engineering, policy, design, and social sciences.

## What is the value added of international network-to-network collaboration for the U.S. research community in the research area(s)? (750 words)

Open source scientific hardware (and the open science movement in which it is situated) is part of a larger social shift characterized by open production methodologies, and decentralized and distributed models of collaboration. Opening up scientific data and tools increases the likelihood that international collaborators will be catalysts to each other's research and enables experimental results to be compared globally. We see added value from a network to network approach across three areas: i) accelerating and advancing research in natural sciences and engineering; ii) STEM pedagogy; iii) social research and STS studies.

### Accelerating and research in natural sciences and engineering

**i) Increased return on investment (ROI) for public research funds:** It is now well established that open source approaches and digital fabrication techniques reduce the cost of high-quality scientific tools to 90-99% as compared to the cost of commercial proprietary equipment.[6] By using an open source hardware designs, the relatively minor development costs result in enormous ROIs for the scientific community: for funders this ranges from hundreds to thousands of percents[7]. This increased ROI is expected to be replicable in different geographic contexts.

**ii) Expanding and advancing additive manufacturing:** The NSF has shaped the rapidly evolving development of additive manufacturing for decades.[8] Many successful OScH projects use additive manufacturing (3D printing) to reduce costs while improving customizability over a wide range of projects including: biological equipment, chemical

[6] Pearce, J. M. (2017). Emerging Business Models for Open Source Hardware. *Journal of Open Hardware*, *1*(1). http://doi.org/10.5334/joh.4
[7] Pearce, J. M. (2015). Return on investment for open source scientific hardware development. *Science and Public Policy*, *43*(2), 192-195.
[8] 3-D printing and custom manufacturing: from concept to classroom. https://nsf.gov/discoveries/disc_summ.jsp?cntn_id=129774

equipment[9] and reactionware[10]. Future NSF support linking other OScH networks could expand this early work to much more sophisticated scientific tools, pushing the boundaries of mechanical and materials design to enable the required precision and functionality.

**iii) Broadening participation in science.** Recently NSF has been promoting open sharing and broader impacts of NSF-supported work. In fact, NSF's core mission to 'promote the progress of science' having open DMP's (Data Management Plans) is well aligned with OScH's mission to lower the barrier to entry for scientific research. A network of networks in OSH would catalyze broader sharing of open source hardware design, usage, and scientific results.

**iv) Collaborating on global open hardware platforms allows shared research questions to be addressed.** OScH tools can be replicated and calibrated against open standards to assist in reducing measurement error and proving experiment reproducibility.[11] This could contribute to more equitable north-south collaborations and increase opportunities for south-south collaboration, allowing research questions to be addressed on shared platforms even where limited resources are a barrier.

## STEM Pedagogy

**v) Synergy with existing NSF programs (e.g., AISL) supporting creative education and a nationwide innovation ecosystem through making:** NSF invests in developing technologies and kits that promote student engagement in design, advanced manufacturing and STEM. Synergistic progress and greater impact could be achieved by promoting greater collaboration and sharing with numerous other U.S. maker networks such as Nation of Makers[12], Make Schools Alliance[13] (network of university makerspaces[14]), and Fab Labs.

**vi) OScH lowers the cost of STEM education in resource constrained contexts from U.S. public schools to universities in developing countries:** Libraries of open source equipment e.g. for optics experiments[15,16] and microscopy[17], have the potential of changing the way scientific techniques are taught in resource constrained communities and to which

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[9] Anzalone, G. C., Glover, A. G., & Pearce, J. M. (2013). Open-source colorimeter. *Sensors*, *13*(4), 5338-5346.
[10] Symes, M. D., Kitson, P. J., Yan, J., Richmond, C. J., Cooper, G. J., Bowman, R. W., ... & Cronin, L. (2012). Integrated 3D-printed reactionware for chemical synthesis and analysis. *Nature Chemistry*, *4*(5), 349-354.
[11] Loken, E., & Gelman, A. (2017). Measurement error and the replication crisis. *Science*, *355*(6325), 584-585.
[12] https://www.nomcon.org/
[13] http://make.xsead.cmu.edu/
[14] http://themakermap.com/
[15] Gwamuri, Jephias, and Joshua M. Pearce. "Open source 3D printers: an appropriate technology for building low cost optics labs for the developing communities." *14th Conference on Education and Training in Optics and Photonics: ETOP 2017*. Vol. 10452. International Society for Optics and Photonics, 2017.
[16] Zhang, C., Anzalone, N. C., Faria, R. P., & Pearce, J. M. (2013). Open-source 3D-printable optics equipment. *PloS one*, *8*(3), e59840.
[17] Chagas, Andre Maia, et al. "The€ 100 lab: A 3D-printable open-source platform for fluorescence microscopy, optogenetics, and accurate temperature control during behaviour of zebrafish, Drosophila, and Caenorhabditis elegans." *PLoS biology* 15.7 (2017): e2002702.

audiences. Studies have shown that 3-D printing is technically viable to make these valuable scientific tools and that the user communities can fully exploit them to improve hand-on STEM learning. These same procedures based on OScH principles can be applied to any area of science and are being implemented by groups like TReND in Africa, who have run workshops for early career African scientists on building and deploying open lab equipment. [18]

## Social Research and STS

**vii) Interest in studying OScH itself is growing rapidly, but there is still very limited research both within and outside academia.**

The global, diverse nature of the OScH community provides unique opportunities for research by science and technology scholars and other researchers. Similar to earlier studies of the Free and Open Source Software (FOSS), a network of networks could support research on i) commons-based peer-production[19], ii) -the development of social networking protocols and services[20] based on hardware, iii) community dynamics at multiple scales and beyond Western European and North American contexts, which are typically overrepresented in FOSS literature. STS scholarship could also develop new analytical frameworks to characterize collaborative practices between grassroots communities, public institutions and companies working on OScH, and analyze power dynamics of gender, socioeconomic status, and technical expertise. More broadly, an OSH network-in-networks would present new methodological insights for studies of open and equitable scientific participation and knowledge sharing.

# What other relevant aspects should NSF consider to strengthen international research networks in the research area(s)? (500 words)

In order to realize the proposed added value, an important consideration is the role of diversity as a key criteria for OScH's success and growth. Mainstream science and technology cultures often exclude minorities and non-english speakers, as well as researchers outside well-funded research institutions. However, broad capabilities and perspectives underpin the potential of OScH to surpass traditional scientific hardware development so greater inclusivity is critical.

Existing international networks formed around OScH such as the Gathering for Open Science Hardware (GOSH)[21] could be strengthened by connections with academic and civil society organizations that serve underrepresented groups and those who could benefit the

[18] https://osf.io/preprints/socarxiv/pyh2r

[19] Benkler, Yochai. 2006. The wealth of networks: How social production transforms markets and freedom. Yale University Press.

[20] Oram, Andy (ed.). 2001. *Peer-to-Peer: Harnessing the Power of Disruptive Technologies*. Sebastopol, CA, USA: O'Reilly & Associates, Inc.

[21] http://openhardware.science/

most from increased access to science and OScH, like community organizers working with people affected by environmental, social, and political issues.

A network of networks approach could overcome some of these challenges and provide more inclusive opportunities by ensuring voices are heard and work is highlighted throughout the ecosystem. For example, the NSF has the opportunity to fund the organization and promotion of online forums and face-to-face activities. Global events, such as GOSH, can encourage international collaborations and enable a wide dissemination of OScH while local and regional events would help overcome language barriers, cost of travel for people who have difficulty securing funds, and cultural differences, thereby enabling development of more context-relevant design and use of hardware.

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Michigan Technological University, Arizona State University, Public Laboratory for Open Technology and Science, The University of Texas at Austin, University of Cambridge (UK), Conservatoire National des Arts et Métiers (France), Universidad Peruana Cayetano Heredia (Peru), University of Tübingen (Germany), University of Tübingen (Germany), Universidad Católica de Chile (Chile)

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