SUPPORTING OPEN HARDWARE FOR OPEN SCIENCE

What is open science hardware?

In the UNESCO Recommendation on Open Science, open hardware refers to "the design specifications of a physical object which are licensed in such a way that said object can be studied, modified, created and distributed by anyone, providing as many people as possible with the ability to construct, remix and share their knowledge of hardware design and function." The term open hardware is derived from open source hardware, and both are used interchangeably in this document.

The Recommendation continues, "In the case of both open source software and hardware, a community-driven process for contribution, attribution and governance is required to enable reuse, improve sustainability and reduce unnecessary duplication of effort. Accompanying software code, description of tools, samples of equipment and equipment itself may be circulated and adapted without restriction, provided that this complies with the national legislation in terms of ensuring safe use." In addition, design decisions, descriptions of research materials, operation manuals or tutorials and designs of equipment may be added to the list of shared resources. Quality assurance standards are a growing part of open science hardware practice.

Other community-derived definitions exist: For the Open Source Hardware Association, open source hardware consists of physical artifacts whose "design is made publicly available with explicit, legally binding freedoms for anyone to study, modify, distribute, make, and sell the design or hardware based on that design" (https://www.oshwa.org/definition/). These freedoms are enabled by applying open source licenses to hardware designs, with the CERN Open Hardware Licenses being the most common.

Open hardware can also refer to a research discipline and the movement involved in the creation and dissemination of accessible hardware that enables the full freedoms for reuse, study, modification, and sharing. Open science hardware refers to open hardware designs used in research contexts.

Closed vs. open hardware

The conventional approach to scientific equipment is based on proprietary (or closed source) hardware, whose designs are restricted by intellectual property systems and cannot be copied or modified. Therefore, the equipment and its design information cannot be openly studied, inspected, maintained, upgraded, customized or easily combined with other hardware.

Scientific advancements and innovations can suffer from this lack of openness. For instance, scientists can be hindered from fully reproducing studies or understanding how their equipment works, which contributes to the replication crisis and causes wasteful duplication of effort—which in turn makes scientific practice more costly or even prohibitively expensive. In addition, if a given private company ends support for their hardware products, it leaves users unable to maintain them, causing further waste of time and money and diminishing the value of investment into research infrastructure.

Beyond these inefficiencies, proprietary designs may contribute to global inequities in knowledge production because the design and manufacturing of scientific equipment are often concentrated in high-resource regions. Restricted access to designs means that only authorized technical services or certified technicians are allowed to repair equipment; these monopolized services are often unavailable locally or are offered at a cost that is prohibitive to the advancement of scientific practice.

Restricted access to designs also means that many scientific tools are created for one context and might not work well in a new setting. This lack of flexibility means that equipment can become obsolete or unusable by design. One-size-fits-all designs reduce the possibility of adapting specific equipment to answer new questions in different contexts/situations, limiting locally meaningful research.

In contrast, OScH practitioners make use of rapid prototyping and digital fabrication tools to test and iteratively refine new ideas and build devices, which are shared through online platforms. Designs available online are at different stages that range from prototypes to more advanced, developed and tested designs, after which a matured design could be mass-produced and distributed.

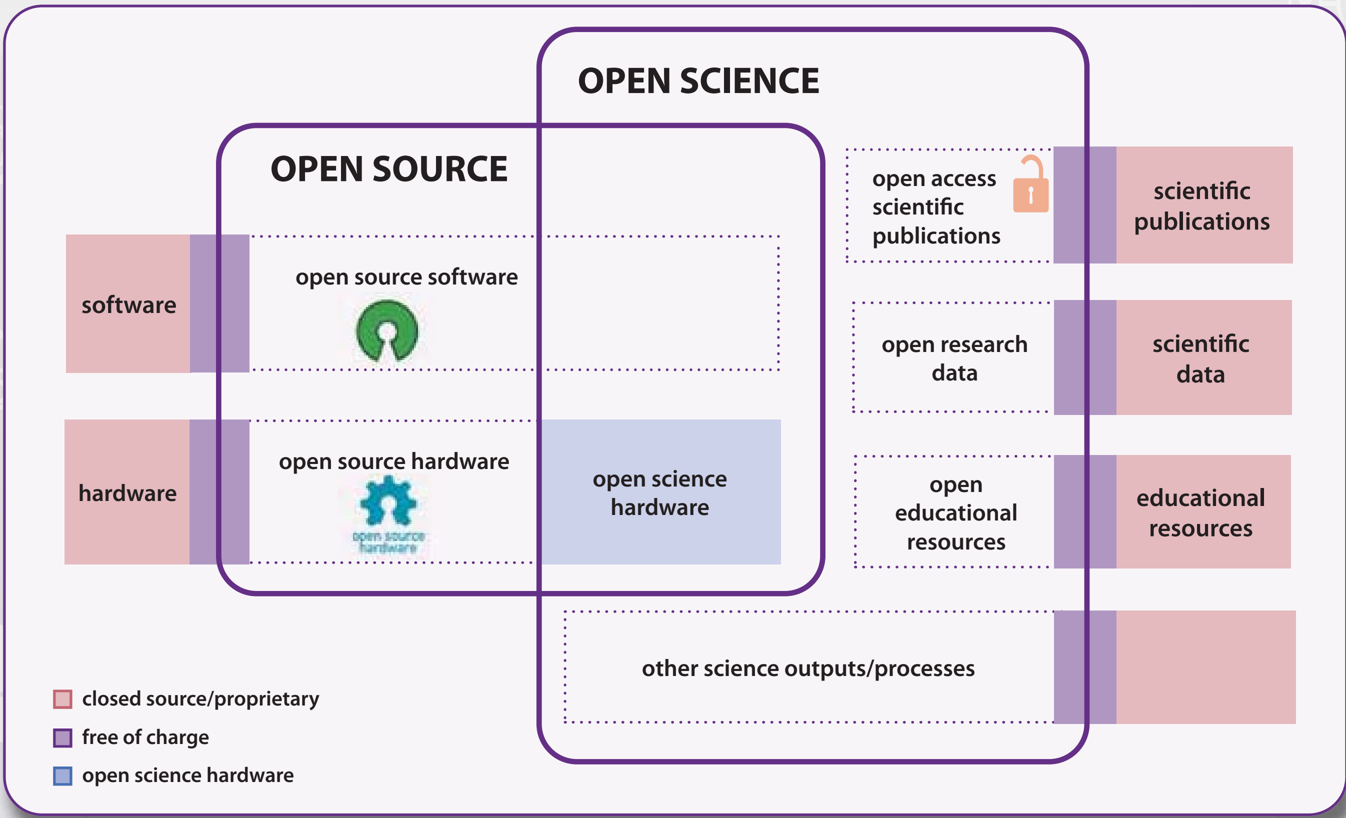
OScH is a field that enables many benefits to scientific practice. Of those, reducing costs is a major benefit. For instance, open science hardware allows researchers to have bespoke scientific equipment at a fraction of the cost of proprietary hardware – which makes science much more accessible and globally democratic. A 2020 review[1] found evidence that, when considering a wide range of scientific tools, open science hardware provides economic savings up to 87% compared to equivalent or lesser-quality proprietary hardware equipment. When a piece of scientific equipment is developed to be open source, the initial investment in the development is converted into a return for the developer or user as these cost savings can be considered to be multiplied by the number of times the tool is replicated. Because many OScH tools have been designed to be digitally replicated, the return on investment can be high in terms of the benefit to the scientific community.[2]

---

[1] See Pearce (2020) Economic savings for scientific free and open source technology: A review. Hardware X 8:E00139, https://doi.org/10.1016/j.ohx.2020.e00139

[2] For one study of return on investment, see Pearce (2016) Return on investment for open source scientific hardware development. Science and Public Policy 43(2):192–195, https://doi.org/10.1093/scipol/scv034

Figure 1. ***Open science hardware, a subset of open source hardware, plays an important role in open science systems. Both closed and open products may be free of charge.***



Who creates and maintains open science hardware?

Open science hardware emerged during the 2010s as an alternative paradigm for research equipment, in response to the problems with proprietary hardware and inspired by the success of open source software and open science ideas.

People around the world are increasingly developing, building and sharing OScH designs in a variety of domains including medical equipment, environmental monitoring, laboratory automation, microscopy and neuroscience research, among others.[3] Many designs are created by academics who need to modify experimental parameters for answering new research questions, or by researchers in need of more accessible and better adapted equipment in low-resource regions.

These communities include educators looking for better tools to use in the classroom, social innovators solving a local need and artists working at the intersection of art and science. When designs are adopted and modified by others, communities of practice also emerge to exchange lessons and improve designs.

Open science hardware is often developed and used in citizen or community science projects that include social scientists, community organizers and facilitators. Such broad participation becomes key for fostering adoption and building a common language between expertise and various sources of knowledge. Conversations between end users, researchers and hardware designers result in co-designed tools that better fit the communities' purposes, contexts and use cases.

[3] A growing set of examples is available; e.g. see https://www.wilsoncenter.org/sciencestack and https://curriculum.openhardware.space/

The scientific community collaborates on open science hardware in different ways, including for example through:

- the Gathering for Open Science Hardware (GOSH), one of the most prominent international networks of OScH practitioners and advocates;
- the Internet of Production Alliance, a global organization convening groups like GOSH together with other OScH community organizations;
- the Open Source Hardware Association (OSHWA), which supports the iterative drafting of a definition and shared set of principles for open source hardware.

The development and deployment of open science hardware is an interdisciplinary endeavor. Collaborations may include, among many others, the end users, researchers who provide domain knowledge, software developers, designers, artists, engineers developing the electronics, manufacturers, and business stakeholders. The growing movement has potential to democratize access to research. However, this change will not happen without support. Institutional leaders, investors, policymakers, librarians, managers of maker spaces or fabrication laboratories ('fab labs'), citizen scientists and others have a crucial role, to play in the development, adoption and management of open hardware for science.

What is needed to fully harness the potential of open science hardware for science and society?

As an integrated dimension of open science, open science hardware can support better, more equitable and efficient knowledge production.

Institutional and governmental support will enable these benefits to be amplified and contribute to solving challenges such as the lack of usability, scalability or performance that burden some proprietary hardware. Moving from prototypes to industrial manufacturing demands additional forms of expertise, such as project management, design for manufacturing, usability, expertise in supply chains, certifications and marketing. A substantial proportion of OScH designs are created in academia and remain in the prototype phase due to a lack of industry support. This is because industrial manufacturing would demand diverse, typically extra-academic expertise and dedicated funding. There is also a need for business partnerships to standardize designs, supporting the process of meeting safety, technical and environmental standards.

Attaining the benefits of open science hardware relies on institutional support from governments, science funders and university administrators as well as engagement of the broader research community and the private sector. As a first step, OScH developers and systems can be supported through:

I. *Incorporation of open science hardware into open science strategies and policies*

By incorporating open science hardware as an integral component of national and institutional open science policies, strategies and mandates, science funders and institutional managers can further promote and foster ongoing voluntary efforts to develop and maintain open science hardware.

Incorporating open science hardware into open science policies can also stimulate its monitoring, and evaluation of its impacts and benefits for local communities.

II. Monitoring and evaluating open science hardware and its impacts

To be able to monitor open science hardware, additional incentives are needed for researchers to share their designs on repositories or databases, with adequate quality control and open source licenses. Funders could require publicly funded designs to be shared through existing repositories currently used for open data and scientific publications, and the use of open documentation standards such as Open Know-How, DIN SPEC 3105 or REUSE can help ensure openness, machine-readability and interoperability.

Moreover, open science hardware designs can also be curated and shared in trusted global repositories, such as those supported by the Digital Public Goods Alliance. Creators and managers can make OScH designs findable through strengthened understanding and adoption of open protocols and standards.

Because diversity among developers and collaborators is key to enabling the creation of designs that are suited to local contexts, monitoring the type and characteristics of developers and collaborators in open science hardware and assessing the composition of the community creating and using open science hardware should also be part of the monitoring framework.

III. Bolstered demand for open science hardware through funding and procurement mechanisms

Reusable open source designs have the potential to significantly magnify the impact of investments made in research. Research funders can maximize the return on investment by incorporating open science hardware as a strong preference, or even a requirement, in grant-making and procurement processes. Examples of this are incentives to using locally manufactured open science hardware in citizen science projects, instead of importing closed source versions from elsewhere. Procurement criteria can include degrees of openness for scientific equipment acquired by sponsored research, leading to increased awareness and adoption of open science hardware.

IV. Recognition of the work of developers and maintainers

The work of those who design and maintain open science hardware, such as contributors to open source designs and early career researchers, is not recognized nor tracked under current career evaluation schemes, particularly in academia. Researchers are therefore only able to capitalize work on inventions when they are patented or licensed in a proprietary way. Patents remain a primary pathway for technology transfer from university research despite the costs of registering and maintaining patents[4]. Researchers are incentivized to keep designs secret even when the designs are not deemed patentable, just in case a design may be considered profitable in future.

Contributions to open science hardware can be incorporated into institutional evaluation and assessment. To realize the full potential of OScH and its built-in freedom for design reuse, there should also be recognition of and incentives for building on existing designs, not just the creation of new ones. Science funders and managers can support open science hardware by recognizing open source hardware licenses as a legitimate, socially responsible and valuable technology transfer option. This recognition could provide a pathway for developers to make their work visible, both by developing and contributing to existing OScH designs. At the same time, this would allow research institutions to track ongoing, overlooked and potentially high-impact work.

V. Support for the development of service centers based on open science hardware

Harnessing available digital manufacturing capabilities in low- and middle-income countries, service centers can become instrumental for efforts to strengthen research capacity. These centers can maintain records

4 See Geuna and Nesta (2006) University patenting and its effects on academic research: The emerging European evidence. Research Policy 35:790–807, https://doi.org/10.1016/j.respol.2006.04.005

of locally available research equipment, spare parts and consumables, harmonizing documentation in local languages while maintaining a library of appropriate OScH designs. Science funders can support the creation of these centers following a self-sustaining model based on provision of consultancy, design and training services to researchers.

VI. *Strengthened capabilities for open science hardware*

Training on open science hardware should be part of open science training for researchers and should build on resources that are already available[5]. Specific capacity building approaches may include:

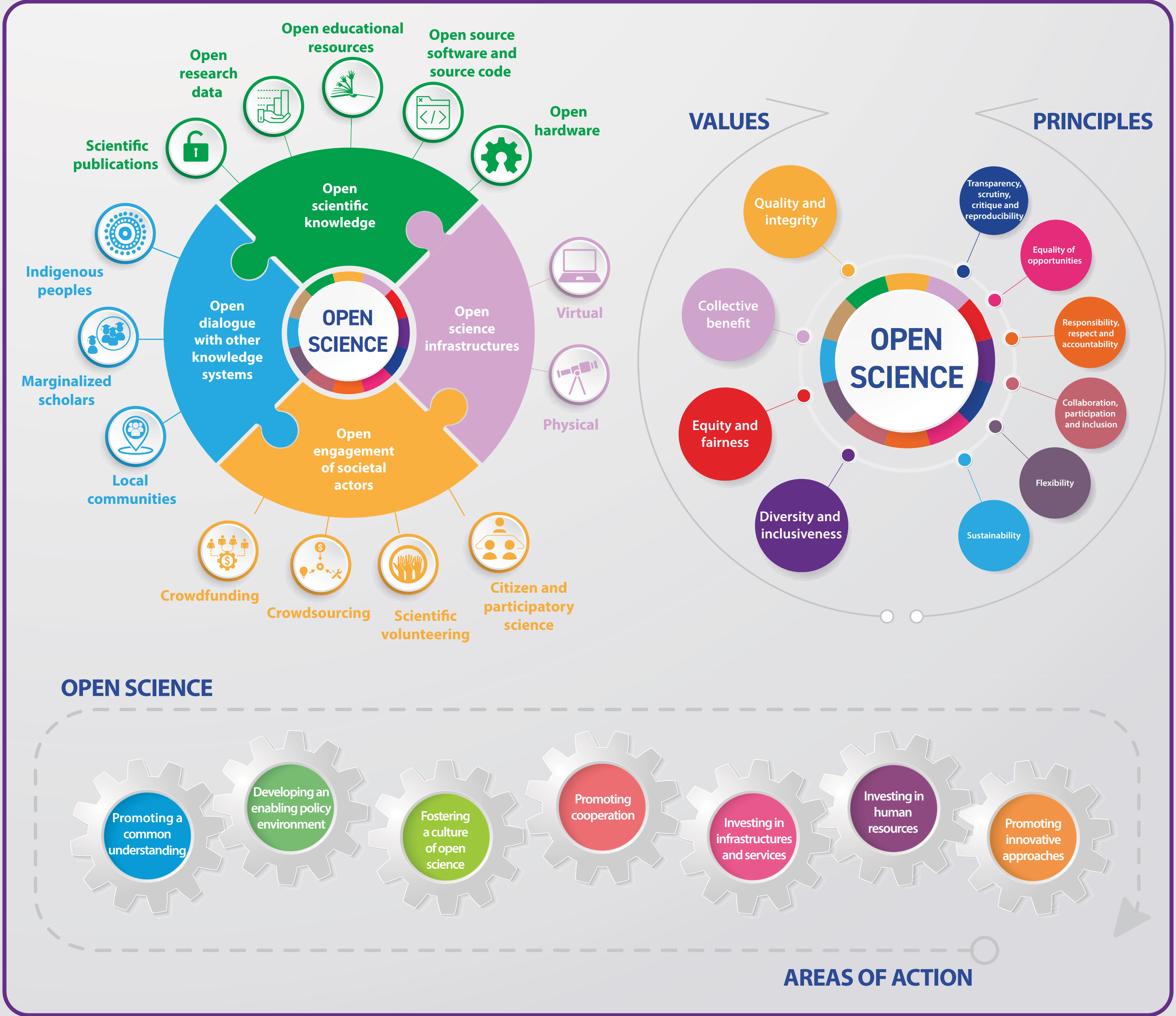
- Raising awareness of open science hardware among students and researchers in STEM fields, providing those who develop hardware with support and mentoring for efficient adoption of open licenses;
- Training technology transfer offices in the use of open source hardware licenses;
- Training scientists who are users of hardware to understand and evaluate open science hardware as an option for research equipment (bolstered by funding practices that incentivize open source products during procurement, see above);
- Increasing awareness of open science hardware and its value beyond STEM subjects to include the social sciences, arts and humanities; and
- Training librarians in open science hardware to better connect developers and potential users of OScH tools within institutions.

These suggested actions are some first steps towards strengthening the role of open science hardware in the research ecosystem. Continuous monitoring of the adoption of open science hardware and regular reviews to develop improved or new policies to nurture open science hardware are essential. When designing and implementing policies, whether to advance open science hardware or other actions under the Recommendation on Open Science, policy makers should also be mindful of research being conducted outside of academia.

[5] For examples, see the open hardware listings in the UNESCO Open Science Capacity Building Index https://www.unesco.org/en/open-science/capacity-building-index

UNESCO Recommendation on Open Science at a Glance

The **Recommendation on Open Science**, the first international standard setting instrument on open science, was adopted by 193 countries in November 2021 at the 41st session of the UNESCO General Conference. The Recommendation provides an internationally agreed definition and a set of shared values and guiding principles for open science. It also identifies a set of actions conducive to a fair and equitable operationalization of open science for all at the individual, institutional, national, regional and international levels.



SC-PBS-STIP/2023/OST/10