JULIETA ARANCIO AND SHANNON DOSEMAGEN

Bringing Open Source to the Global Lab Bench

In 2015, Richard Bowman, an optics scientist, began experimenting with 3D printing a microscope as a single piece in order to reduce the time and effort of reproducing the design. Soon after, he started the OpenFlexure project, an open-license 3D-printed microscope. The project quickly took over his research agenda and grew into a global community of hundreds of users and developers, including professional scientists, hobbyists, community scientists, clinical researchers, and teachers. Anyone with access to a 3D printer can download open-source files from the internet to create microscopes that can be used for doing soil science research, detecting diseases such as malaria, or teaching microbiology, among other things. Today, the project is supported by a core team at the Universities of Bath and Cambridge in the United Kingdom, as well as in Tanzania by the Ifakara Health Institute and Bongo Tech & Research Labs, an engineering company.

OpenFlexure is one of many open science hardware projects that are championed by the Gathering for Open Science Hardware (GOSH), a transnational network of open science hardware advocates. Although there are differences in practice, open hardware projects operate on similar principles to open-source software, and they span disciplines ranging from nanotechnology to environmental monitoring. GOSH defines the field as "any piece of hardware used for scientific investigations that can be obtained, assembled, used, studied, modified, shared, and sold by anyone. It includes standard lab equipment as well as auxiliary materials, such as sensors, biological reagents, analog and digital electronic components." Compared to an off-the-shelf microscope, which may cost thousands of dollars, an OpenFlexure microscope may cost a few hundred. By being significantly cheaper and easier to maintain, open hardware enables more people in more places to do science.

The academic production of open hardware has increased exponentially in the last five years with the emergence of networks, dedicated publication venues, peer-reviewed literature, and thematic events, all aimed at supporting open science hardware projects. Successful projects have led to greater access to equipment, which increases research efficiency, and have fostered equity and public participation in science. However, open hardware is still the exception in science, and the designs of most research tools remain unavailable to their users, which limits their accessibility and adaptability. Encouraging broader use of open science hardware will require funding agencies, universities, and international organizations to cooperate and incentivize researchers to develop and share hardware designs.

Open hardware solves an access problem and produces better science tools

Open hardware addresses a significant hurdle for global scientists: science equipment is often expensive to purchase and difficult or impossible to customize or repair. New research questions—or questions in new research settings—often require that tools be modified or customized. Lack of access to designs makes tools more difficult to customize, leading to delays and additional costs.

Historically, science hardware manufacturing has been concentrated in well-resourced countries, making it unreasonably difficult and expensive to obtain and repair elsewhere. As a result, researchers, educators, and others outside academia and at the periphery of these production centers find it almost impossible to access and maintain research infrastructure. The World Health Organization estimates that 70% of donated medical equipment in sub-Saharan Africa is out of service or not in use due to lack of authorized service engineers and necessary parts.

Research shows that the relatively small development costs of using an open hardware design result in a significant return on investment for the scientific community. Studies have demonstrated that on average, open-source tools provide economic savings of 87% as compared to proprietary tools.

But the true gains from open hardware may be significantly greater. Syringe pumps, for example, are used to deliver carefully controlled doses of reagents in many laboratory applications. Substituting an open hardware pump for a commercial one saved up to $2,500, a 2016 study found. When multiplied by the number of times the open-source pump designs have been downloaded by users, the study estimated total savings of potentially millions of dollars, even when factoring in the cost of developing and sharing the open-source designs. This return accrues both to researchers, who save money on equipment, and to funders, for whom the returns are compounded when designs are shared and reproduced.

A new way of thinking about scientific tools

Making the designs of scientific tools publicly accessible not only provides transparency into research, design, and prototyping or manufacturing processes, but also opens new innovation opportunities. In the case of OpenFlexure, anyone can download the microscope's source files, including those needed for 3D-printing the parts and the software that powers it. Detailed documentation helps others to print, assemble, and use their own devices. The community gathers in an online forum to exchange building lessons and their user experiences, allowing for faster innovation and new uses and applications for the designs.

Open hardware also invites more people into science by empowering diverse groups to engage with the public to create knowledge. In Argentina, for example, a group of academics, family farmers, and activists used open hardware to form an "open agroecology lab." Lab participants adapt these tools to support local research on soil health, a line of inquiry that is overlooked by official research agendas dominated by industrial agriculture. Using OpenFlexure and other open hardware tools, the group is studying the response of soil microbes to more natural ecological production models, aiming to build a body of knowledge for regional farmers who wish to convert to more environmentally friendly farming methods.

Finally, open-source hardware also contributes to the growth of entrepreneurially minded service companies that are able to manufacture hardware using publicly accessible designs, offering users ready-to-use tools and technical support in many local contexts. This reduces risk for research teams, as designs will remain available even if a supplier goes out of business. By producing and commercializing science hardware locally and using accessible materials, these companies are increasing access to science equipment in settings where the tools of science are not readily available.

Increasing open science hardware requires policy support

Despite the enormous potential of open science hardware, today the field largely reflects voluntary efforts, extremely limited financial support, and the short time horizons of the funding that is available.

Making open science hardware more widely available will require active policy support. Funding tends to be more readily offered for "breakthroughs" and first-of-their-kind ideas, but is comparatively scant for infrastructure and its maintenance. Recent recommendations from organizations such as UNESCO in support of open science practices are encouraging; however, more inclusive public participation in science requires more than making the products of research, such as data and publications, accessible. Knowledge production itself must be opened up. One way to achieve that is by making the tools needed for performing and teaching science more accessible.

Recognizing the need for institutional support, members of GOSH convened a series of policy workshops in 2021 targeting government agencies and science funders, international organizations, and universities and their technology transfer offices (TTOs). This included a policy workshop for US audiences alongside the Wilson Center Science and Technology Innovation Program. These discussions resulted in a series of policy recommendations for each group.

Government agencies and science funders, including private foundations, have a role to play by incentivizing the development, dissemination, and use of open hardware. Funding agencies could, for example, encourage researchers to seek open hardware when including requests for equipment in their proposals, incentivizing the development of open hardware companies. Since open hardware tends to be lower cost than proprietary hardware, this could have the added benefit of making federal research dollars stretch further.

Many funders already support initiatives to encourage diversity, critical skills growth, and career incentives, and open hardware can be explicitly linked to these goals. Funders could also incentivize researchers to make any products or tools developed during funded research open and available. In this way, funders could create a culture where open research is the norm rather than the exception.

International organizations, such as humanitarian and aid groups or nonprofits working in education, can increase their innovation capacity by adopting and promoting open hardware. Like funders, they can include open science hardware in the research they conduct and support. For example, UNICEF's Innovation Fund provides funding to start-ups developing new open-source solutions that will benefit children. One of the fund's projects is the development of open drone-based technologies and services for a range of applications, including vaccine delivery and transport, improved connectivity in hard-to-reach communities, and aerial imaging for better emergency preparedness and response.

As a major source of open science hardware designs, universities could also include open hardware in curricula to enable students from diverse backgrounds to learn through doing. Open science hardware practitioners across the sciences have developed additional, specific recommendations for ways these priorities can be addressed in both the short and long term.

University TTOs—which facilitate the process of taking university research and innovations to market, acting as a channel between academia and industry—are in a privileged position to foster open hardware adoption, which would increase the impact of already-existing research. But this will require a cultural shift away from only prioritizing patentable inventions; the current patent-and-license paradigm misses opportunities for impact. TTOs could move toward a diversified portfolio that includes open hardware licenses as a valued transfer tool, supporting academic researchers who wish to openly license their inventions. Such a change requires university leaders to reorient their TTOs toward a broader mission. A network of open hardware-friendly TTOs would accelerate the transition by promoting collaborations while highlighting the members' innovative approach to technology transfer.

Infrastructure for innovation and equity

Beyond facilitating more efficient research, open science hardware provides a framework for envisioning and working toward more just infrastructure—and more equitable access to science and its tools, methods, and processes. The experience of early adopters of open hardware demonstrates that it can foster mission-oriented, multiscale collaborations among academia, civil society, governments, and industry.

Policy discussions in science and innovation tend to reinforce the individual, technology-driven angle of "solutions" to society's most urgent challenges. Instead, open hardware offers a different perspective on science and innovation, recognizing the collaborative nature of science infrastructure as well as the communities of scientists, developers, community managers, technicians, and users that sustain research over time. By allowing multiple perspectives and needs to materialize in research equipment, open hardware can become a powerful tool for transforming power dynamics in knowledge production, offering a glimpse of what more efficient—and more inclusive—research could look like in the near future.

Research shows that the relatively small development costs of using an open hardware design result in a significant return on investment for the scientific community.

To enable this vision, policymakers, funders, and academic institutions should make open hardware a principle of innovation programs and standards, align funding and incentives, and raise awareness through research, education, and training initiatives. These concrete steps can transform open hardware into a strategy for achieving the paradigm of global collaborative science and innovation.

Julieta Arancio *is a postdoctoral researcher at Drexel University and a cofounding member of the free-libre technologies for science and education in Latin America (reGOSH) network.* ***Shannon Dosemagen*** *is a Shuttleworth Foundation fellow directing the Open Environmental Data Project and a cofounding member of the Gathering for Open Science Hardware.*