Federal Flagship Programs:

Case Studies of Federal Involvement in Tools for Open Science

Authors

Abigail Lambert
The Wilson Center

Alexandra Novak
The Wilson Center and Columbia University

Alison Parker
The Wilson Center

Table of Contents

Authors

Abigail Lambert
Research Intern, Science and Technology Innovation Program, The Wilson Center

Alexandra Novak
Research Analyst, Science and Technology Innovation Program, The Wilson Center

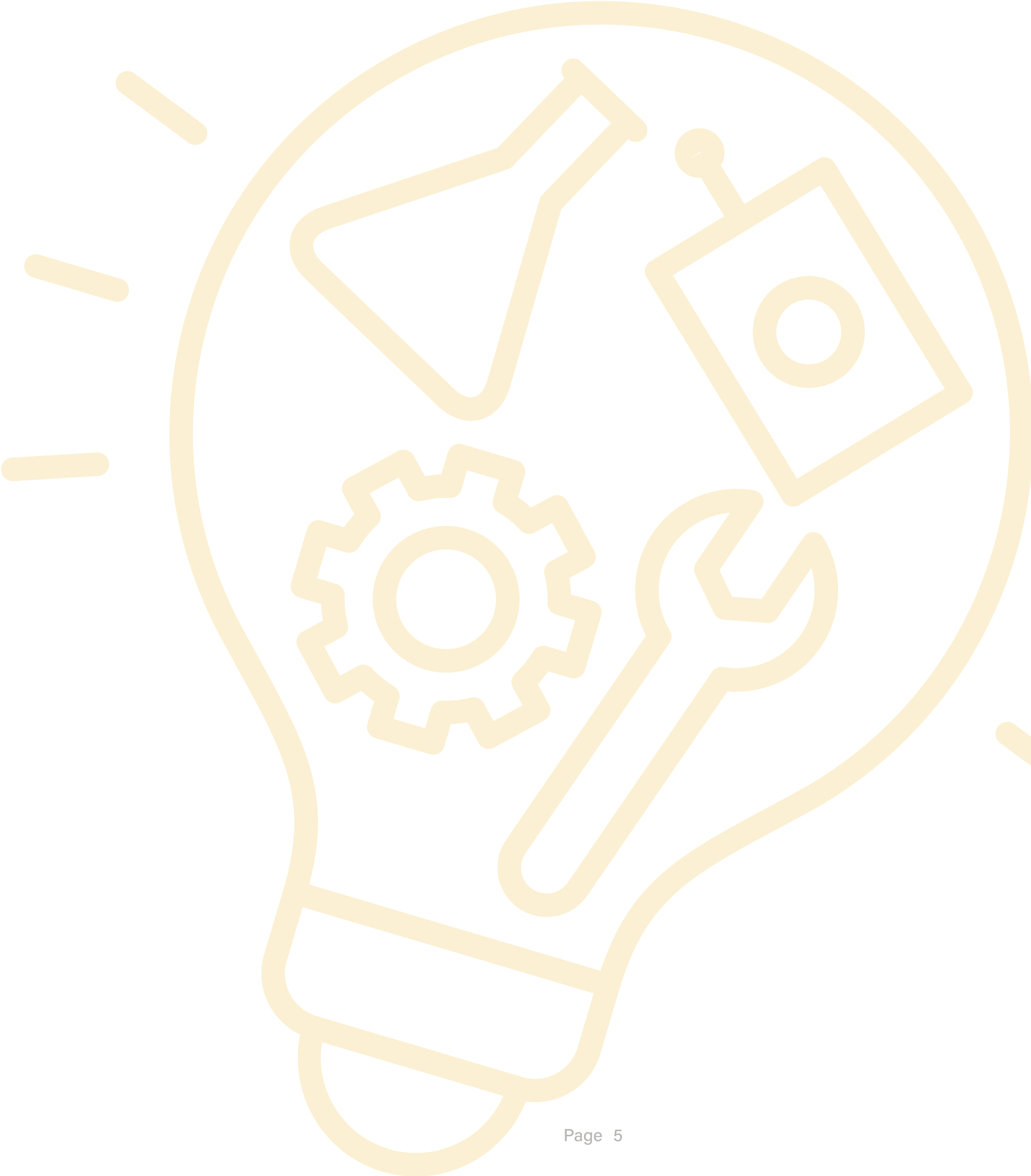
Alison Parker
Senior Program Associate, Science and Technology Innovation Program, The Wilson Center

Wilson Center

Executive Summary

With increased enthusiasm for open science, there is both a need for, and greater uptake of, low-cost and open source tools used for open science. Although academic and non-profit sectors are the primary drivers of advancements in tools for open science, the federal government is inextricably linked to open science in the United States, from contributing to the development of scientific tools, to making scientific data and research openly available, to developing programs and funding opportunities.

This report explores 13 cases of federal projects and programs, exploring how they support tools for open science, how these tools are making science more open, and the feedback, barriers, and outcomes that come alongside.

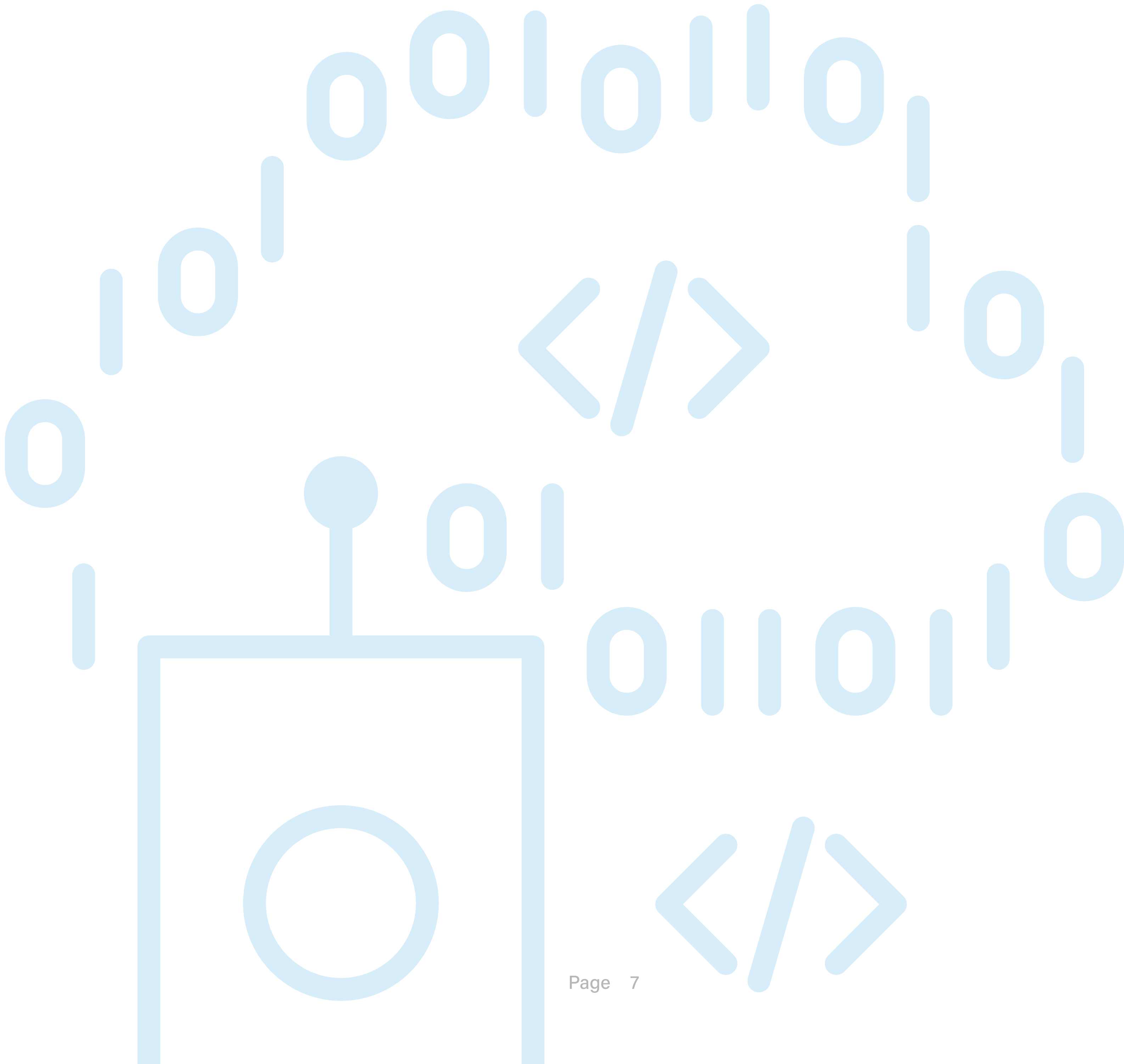


Introduction

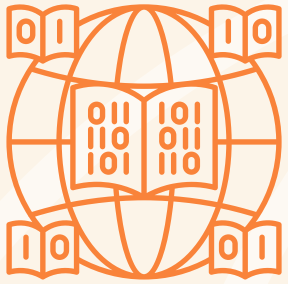
According to the White House Office of Science and Technology Policy and the National Science and Technology Council, open science is "the principle and practice of making research products and processes available to all, while respecting diverse cultures, maintaining security and privacy, and fostering collaborations, reproducibility, and equity." Open science has significant implications for scientific research, as it allows researchers to collaborate and build upon each other's work in a more accessible and cost-effective way. By making publications, methods, data, and tools publicly available, open science improves scientists ability to reproduce and validate studies. This transparency also increases equity, by removing paywalls to papers and resources, lowering the cost of tools, and enabling more diverse audiences to participate in science. As the open science movement grows in the United States and globally, the practice of creating and using physical tools or hardware for open science—both low-cost and open source—is growing too.

Tools for open science range from building blocks of other tools, such as microprocessors and 3D printers, to tools that collect data, such as microscopes, air quality sensors, and small satellites. As noted in Building Blocks for Better Science, a set of 16 case studies, this range of tools is accelerating scientific progress and broadening participation in science (Parker & Novak, 2020). Some tools for science are more available to all due simply by being low-cost alternatives to traditional tools. Some of these tools are significantly less expensive, to the extent that they drastically change accessibility and use. This includes do-it-yourself (DIY) tools, tools developed by makers and in makerspaces, commercial off-the-shelf hardware, and mixed solutions containing both proprietary and open components. Many low-cost tools were designed to be easy to set up and use. For example, **PocketLab** produces are portable sensors for collecting physics, weather, and air quality data. Due to their ease of use, teachers and students without technical backgrounds are able to use them for STEM education. Similarly, **Purple Air**, a low-cost particulate matter sensor, has broadened participation in air quality monitoring to many individuals and communities.

Other tools are more available to all in that they are designed and distributed in a way that explicitly fosters openness, collaboration, and re-use, aligning with the principles of open source and permitting the distribution of designs and documentation. These tools are considered open source hardware, defined by the **Open Source Hardware Association** as "a term for tangible artifacts—machines, devices, or other physical things—whose design has been released to the public in such a way that anyone can make, modify, distribute, and use those things." Open source hardware builds a library of tools that can be reproduced, refined, and improved on, creating opportunities for further innovation and avoiding "reinventing the wheel" (Hill, 2021). Open source hardware also results in multiplicative collaboration and impact (Häuer, 2021). **Arduino**, for example, spurs the invention of new tools and use cases, as well as builds strong communities by allowing participation at all stages of tool development as well as enabling anyone to build on or reproduce it.

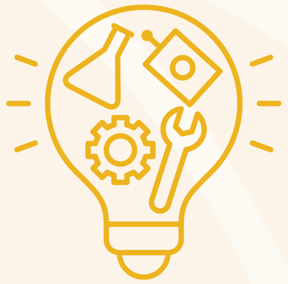


THROUGHOUT THIS REPORT, WE USED ICONS TO REPRESENT SOME OF THE DIVERSITY OF OPEN SCIENCE PARADIGMS PRESENT IN GOVERNMENT INITIATIVES.



Open Access

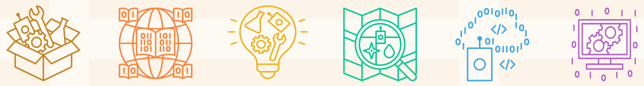
Scientific documents, publications, and other written research products that are available for anyone to access and share free of charge (Open access.nl, n.d.).



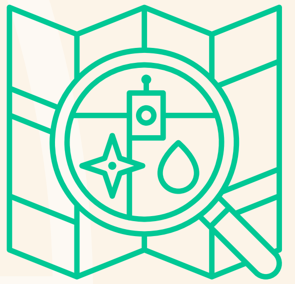
Open Innovation

The use of external ideas to advance and inform internal innovation processes (Chesbrough, 2006).

Open Science



"The principle and practice of making research products and processes available to all, while respecting diverse cultures, maintaining security and privacy, and fostering collaborations, reproducibility, and equity" (OSTP, 2023).



Citizen/Community Science

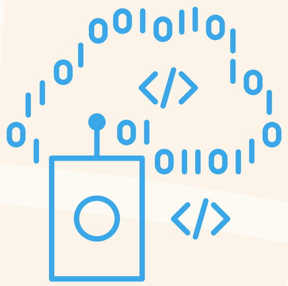
Public participation in the scientific process, from data collection to result analysis, to answer specific research questions, pursue new knowledge, or enable evidence-based decision making (Citizen Science Association, n.d.).

Open Source Hardware

Physical tools "whose design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design" (Open Source Hardware Association, n.d.).

Open Source Software

Software whose code is made open to the public for anyone to examine, alter, distribute, reproduce, and sell (Open Source Initiative, n.d.).



Open Data

Data that is open for the public to discover, access, use, and share (Data Europa EU, n.d.).

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Bridging Communities & Institutionalizing Open Source

The federal government supports tools for open science programs in many ways. Through our analysis of the case studies, we identified the following categories of federal involvement. These are labeled with tabs on the right side of each case study:

- Funding
- Proposal, design, or initiation
- Tool design
- Product testing and quality assurance
- Tool or document distribution
- Maintenance
- Training
- Community, research or educational resources
- Partnership establishment/maintenance

Innovators in the academic and non-profit sectors are the primary drivers of advancements in open tools, whereas government initiatives so far are less involved. However, the advantages that open science and, specifically, open tools provide align with federal agency missions. By avoiding re-inventing the wheel, using open science and open tools provides a better return on investment for federal funding. Open science and open tools also increase transparency and participation in science, which could help agencies better serve and engage with their

Image: NASA Education Stakeholder's Summit (201009130012HQ)" by NASA HQ PHOTO is licensed under CC BY-NC-ND 2.0

communities and increase public trust in U.S. science. This participation in science can also accelerate innovation, helping agencies meet their mission.

In addition to leveraging the unique benefits of open science and open tools, the federal government is in a unique position to foster open tools for maximum impact. Federal government staff can use tools for open science to support their work in the service of agency missions; science agencies can support the development of open tools through grants and innovative mechanisms like prize and challenge competitions. Perhaps most importantly, government can play a key role in providing the infrastructure for open tools and open science practices.

There are various forms of infrastructure, from knowledge resources to frameworks to

services, that can broadly support the creation and use of tools for open science. Federal institutions can play a role in developing new standards for or assessing data quality of tools for open science, serving as an authoritative voice. They can also be involved in intellectual property and licensing, which currently tends to exclude open source hardware. Other forms of support by federal players in sustaining open networks and organizations is through digital infrastructure, technical assistance, financing, and commercialization support.

Recently, the Biden Administration's Office of Science, Technology, Policy (OSTP) cemented a federal role for open science by designating 2023 as the Year of Open Science (OSTP, 2023). This initiative aims to highlight the importance of open science and encourage government agencies, private entities, and academic institutions to adopt its principles and practices.

However, institutional support, particularly at the federal level, is both a current challenge and potential accelerator for tools for open science. For example, during the initial stages of the COVID-19 pandemic, grassroots and open source hardware communities mobilized to address shortages of personal protective and medical equipment. Federal players were able to organize a review process on the fly to assess equipment designed by grassroots communities for clinical use. However, a lack of precedent, intentional planning, and existing

Image: "44070151880" by open hardware summit is licensed under CC BY 2.0

processes for collaboration between federal institutions and grassroots communities inhibited the speed and scale at which the personal protective and medical equipment could be distributed to those with acute need. (Bowser et al., 2021)

In this report, we examine 13 projects and programs describing how the federal government is involved in tools for open science, from supporting specific tools to developing broader open science initiatives. By looking at these examples, we can understand how federal practitioners have been involved in these initiatives, under what conditions, and what impact they have had. We can also identify future areas where federal support is needed as well as where current support is misdirected. Through this analysis, we hope to identify the physical, technical, and social infrastructure needed for policy audiences to fully embrace open source hardware and other tools for open science.

Project PANOPTES

VISIT WEBSITE

Communities / agencies involved:

- National Aeronautics and Space Administrationand Jet Propulsion Laboratory (NASA JPL) funded
- Astronomers and researchers at universities
- Students and educators
- Affiliated team members: projectpanoptes.org/people

Overview

Project PANOPTES, the Panoptic Astronomical Networked Observatories for a Public Transiting Exoplanets Survey, is a citizen science project that aims to make it easy for anyone to build a low-cost, robotic telescope and establish a worldwide network of small cameras to detect exoplanets. Teams range from astronomy researchers to middle school science students and are currently in various building and implementation phases.

How and when was it developed?

This project began in 2010 with the prototype development, which served as the baseline unit for the development of additional PANOPTES units around the world (Guyon, Walawender, & Butterfield, n.d.). NASA's JPL supported Project PANOPTES from 2015-2020 through a Universe of Learning grant. This project also had partnerships with Caltech, Smithsonian Astrophysical Observatory, and Sonoma State University.

What is it?

The PANOPTES hardware and software design principally uses commercially available parts to ensure telescopes are inexpensive and easily acquired. The PANOPTES was designed to allow for a simple building process and a reliable final product. In total, the exoplanet finding telescope can be built for about $5000. In addition to publicly available tools and building instructions, all project software is also open source and available on GitHub. Building a PANOPTES telescope may only take a few weeks, but can be extended and supplemented with educational lessons for longer-term school projects. The first baseline unit, PAN001, is located near the summit of Mauna Loa on the Big Island of Hawai'i.

How it's making science more open

This initiative was created as a citizen science project to encourage student and budding scientist involvement. Designers have emphasized the importance of educational lesson plans for further engagement with the technology. There is an updated community forum for anyone interested in building or learning more about Project PANOPTES, which has information on troubleshooting, project ideas, and science related to exoplanets. Teams come from a range of locations and backgrounds, including Hawai'i, Europe, Australia, and South America. There is also a Google Group for further communication and engagement across teams.

Outcome, feedback, and barriers

Since its inception, the project has hosted 18+ teams around the world in building a robotic telescope. The community forum for Project PANOPTES is still active, with several posts in the last year from students or researchers requesting information on building a PANOPTES unit. Several community members have also added information on technical modifications and PANOPTES team members respond quickly to troubleshooting questions. Some of the project teams that have finished telescopes reported modifications or delays related to weather-proofing or tracking systems. In addition, several researchers involved in the project remarked on the challenges of this project in a conference presentation titled "Project PANOPTES: the good, the bad, and the ugly challenges of running a successful Pro-Am astronomy project (Gee et al., 2018)." PANOPTES team members noted the difficulty of sustaining a project with no specific institutional home or no official operating budget, besides support from each team.

> **"PANOPTES team members noted the difficulty of sustaining a project with no specific institutional home or no official operating budget, besides support from each team."**

Image: "File:NARIT Robotic Telescope in Chile.jpg" by JulladaNARIT is licensed under CC BY-SA 4.0.

Image: "Building a Space Telescope" by Kevin Harber is licensed under CC BY-NC-ND 2.0

Foldscope

VISIT WEBSITE

Communities / agencies involved:
- Foldscope Instruments, Inc.
- National Institutes of Health (NIH)
- National Science Foundation (NSF)
- Global user community
- Several philanthropic foundations

Overview

The Foldscope is an ultra-low-cost origami-based microscope that allows for large-scale manufacturing and broad public use (Parker & Novak, 2020).

How and when was it developed?

The Foldscope was invented in 2012 by Manu Prakash and Jim Cybulski, two Stanford University researchers. The tool was created in response to how expensive and bulky traditional microscopes were, with the goal to design one that was both cheaper and more accessible. They were motivated by developing a microscope that could be built for under $1. The team successfully achieved this mission with the Foldscope, which can be made almost entirely of paper. The pilot program occurred in 2014 with funds from Stanford University's Spectrum Medtech, the Moore Foundation, and the Coulter Foundation (Cybulski, Clements, & Prakash, 2014). Since then, global distribution has rapidly increased and the microscope is used by a variety of users and in many different scientific and educational settings. The NIH supported various stages of development through research grants and researcher fellowships.

The success of the foldscope technology led to the creation of Foldscope Instruments, Inc. in 2015, which aimed to scale up production and eventually release more low-cost scientific tools. At first, the developers decided to create and distribute 10,000 free foldscopes to users to test the technology. The demand for these microscopes was larger than expected and they increased production to 75,000 after receiving a grant from NSF.

What is it?

Foldscope is a portable, durable, low-cost paper microscope that reaches the magnification and resolution of some more expensive microscopes. The developers wanted to quell the notion that microscopes must be expensive and complex instruments, so the tool can be produced for $1 in parts. Due to its accessibility, it is widely used.

How it's making science more open

As of 2022, over 1.7 million Foldscopes have been distributed to communities in over 160 countries. The users have various levels of scientific training, ages, and backgrounds. Purchasers include a wide range, from grandparents looking for an inexpensive gift to people wanting to diagnose the disease of their honeybees (Cohen, 2014). Foldscope recently reported that over 400 scientific papers have been published using data collected with the Foldscope, including the discovery of two new species. Foldscope has also created Microcosmos, a platform where users can connect and post observations, questions, or ideas. Users can see other projects going on around the world and learn from the successes and challenges of prior uses. In addition, Foldscope promotes grassroots mentoring, open sharing, and more equitable access to scientific tools around the world. There are lesson plans and workshops publicly available, as well as training services in several languages (Foldscope Instruments, n.d.).

Outcome, feedback, and barriers

Foldscope continues to grow in the size of its user base and diversity of use. The company plans to distribute one million more foldscopes to communities around the world. In 2022, Foldscope won the Golden Goose Award, which recognizes a federally-funded scientific project with an impact on society (The Golden Goose Award, 2022).

One of the current challenges of Foldscope Inc. is the costs associated with getting the foldscope from the factory to the customer–which is more costly than manufacturing the tool itself. According to the creators, U.S. government support in the development of manufacturing and distribution strategies could help minimize some of these challenging costs. Federal support in creating a more streamlined channel for user testing and feedback would also further connections and new innovations

Image: "Creator of the Foldscope" by National Center for Advancing Translational Science is licensed under Public Domain Mark 1.0

within the Foldscope user community. While the Foldscope continues to expand in its reach, Prakash's research team at Stanford has been developing other low-cost tools for science. The Paperfuge is a paper centrifuge that can separate pure plasma from a sample of blood in a minute and a half, and the Octopi is a low-cost autonomous microscope that can identify malaria in blood samples.

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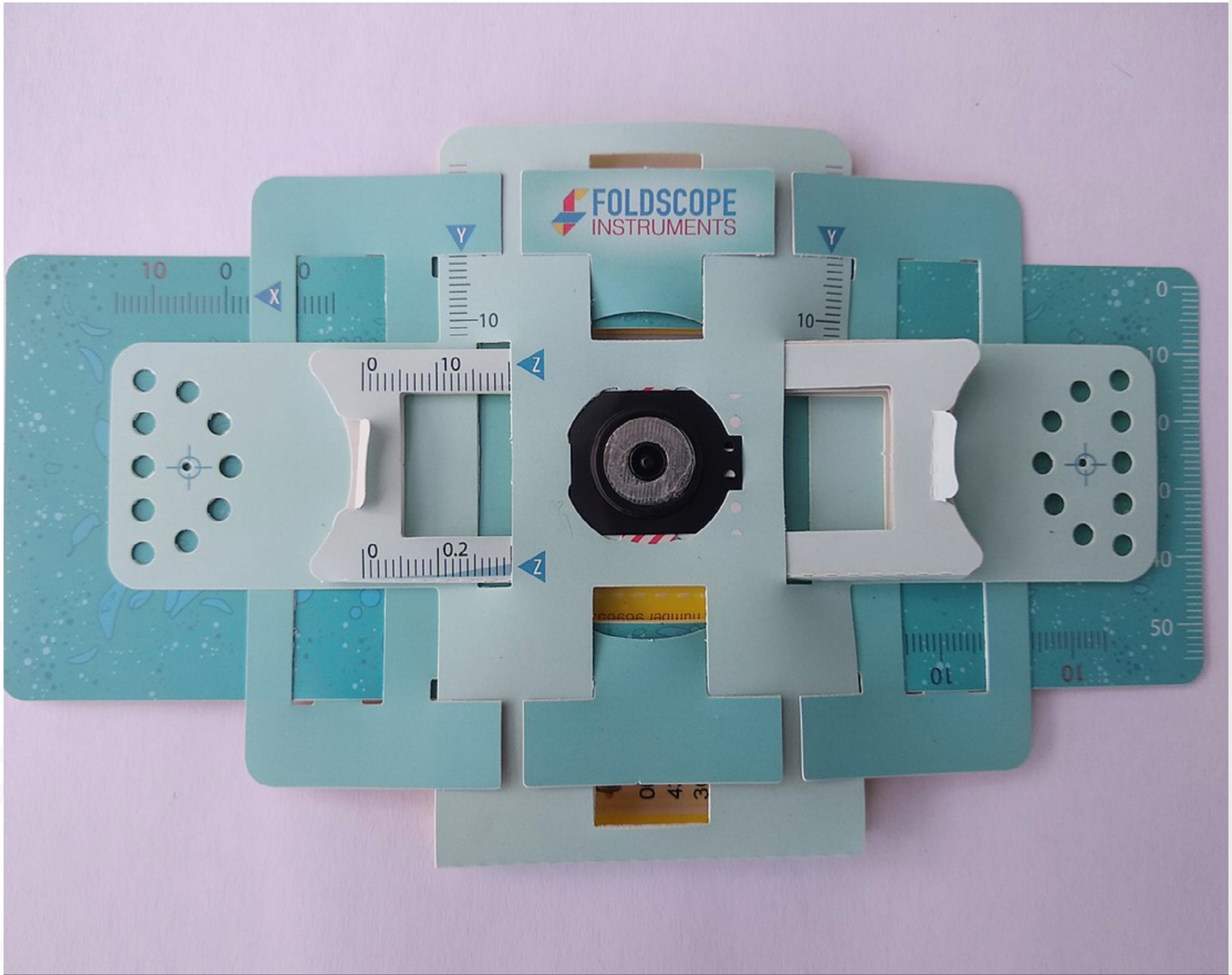

Image: "Aufgebautes Foldscope.jpg" by Sockenpaket is licensed under CC BY-SA 4.0.

U.S. DOE Solar Desalination Prize

VISIT WEBSITE

Communities / agencies involved:

- Solar Energy Technologies Office at the Department of Energy (DOE)
- Individuals, companies, and research groups who entered the prize competition such as Planet A Energy, SolMem, and Team Trident.
- International Desalination Association (IDA) Students and educators

Overview

The Solar Desalination Prize, one of the U.S. DOE's American-Made Prize Challenges, seeks to accelerate the production of low-cost desalination systems run by solar-thermal power.

How and when was it developed?

The Solar Desalination Prize kicked off in 2020 and involves four rounds of testing and demonstration of technologies, with prize money awarded in each stage. It is one of many prize and challenge competitions sponsored by the federal government to reward non-federally affiliated groups for scientific innovations and research.

What is it?

This American-Made Challenge is specifically focused on allowing U.S. innovators to develop clean energy technology that will make the U.S. energy grid more reliable and resilient. Throughout each round, the teams work to determine the technical feasibility, scalability, and other potential benefits of the proposed solution. In the semifinalist round, each team received $250,000 and a $100,000 technical assistance voucher to be redeemed at a National Laboratory or American-Made Network partner organization. National Renewable Energy Lab (NREL) administers the competitions and awards grants but does not

Image: "Solar Desalination Prize finalist Katz Water Technologies team testing the solar desalination system at their Houston testing facility" by John (Juan) Doria, all rights reserved.

oversee the technology development itself. The prize aims for a low barrier of entry by having an application process that only requires a 90-second video pitch, a summary slide, and a five-page application describing the challenge, proposed technical solution, team, and plan. The technologies were all designed to be low-cost and easy to use, with the ability to be deployed to a range of locations around the world. One semifinalist, Planet A Energy: Solar Heat Collector With Built-in Storage,

Image: "Daniel Vasek of Solar Desalination Prize finalist team Katz Water Technologies is testing the Multi-effect Distillation X-VAP distillation system inside KWT's Houston Warehouse" by Gary Katz, all rights reserved.

combined a low-cost solar collector with a low-cost thermal energy storage material that the solar collector directly heats.

How it's making science more open

There are many water resources in the U.S. and globally that cannot be cost-effectively used because of high concentrations of dissolved salts. This prize competition involves non-profits, students, small businesses, and research teams in addressing this pressing issue. Anyone could pitch their idea and prizes are awarded based on the merit of the technology, rather than affiliation or influence. These challenges provide financial support, capacity, and credibility to non-federal innovators and encourage further collaboration among the private and public sectors.

Outcome, feedback, and barriers

Since DOE launched the Solar Desalination Prize competition in 2020, there have been two successful challenge rounds and millions of dollars awarded. An effective pay-for-performance incentive structure facilitated diverse expertise and interdisciplinary collaboration. While Round 2 is still underway, it is currently difficult to access recent updates from the competitors. Federal prize administrators do not oversee the technology development post-challenge, making it difficult to assess the long-term success and viable application of the technologies developed during these challenges. Some teams continue to collaborate and commercialize the technologies after the competition, while other teams have dropped off the radar or never fully developed their hardware.

"Anyone could pitch their idea and prizes are awarded based on the merit of the technology, rather than affiliation or influence. These challenges provide financial support, capacity, and credibility to non-federal innovators and encourage further collaboration among the private and public sectors."

First Responder Unmanned Aircraft System (UAS) Endurance Challenge

VISIT WEBSITE

Communities / agencies involved:

- National Institute of Standards and Technology (NIST)
- UAS engineers, researchers, and students
- Public safety personnel

Overview

NIST runs the First Responder UAS Endurance Challenge, which facilitates R&D for efficient, cost-effective, and flexible UAS designs.

How and when was it developed?

In 2020, forty-three teams participated in the UAS Endurance Challenge. Throughout the competition, five final teams spent 14 months designing and building a lightweight UAS. Competitors, such as the winning Team AAC (Advanced Aircraft Company), iterated prototypes during four stages with the goals of optimizing payload, energy source, and flight times for UAS technology. The teams ultimately competed for a prize of up to $588,000 and a chance to showcase their designs live for the NIST judges and first responders.

What is it?

Drone technology is increasingly regarded as critical for communication on search and rescue operations and public safety missions. This prize competition is part of the Public Safety Communications Research (PSCR) Open Innovation Program, which seeks to innovate technology solutions through rapid

Image: "Risks-of-Consumer-SIM-cards-for-drone-operations.jpg" by UAV.gov is licensed under Public Domain.

and collaborative methods. The winner of the competition, Team AAC, specializes in building drones that enable longer flight times for safety missions through their hybrid-electric propeller system. The drones are quick to set up and easy to use for their customers, especially for members of the public safety community. Competition participants had the chance to work directly with the public safety users of these technologies who provided feedback on the designs. The drone designs were much

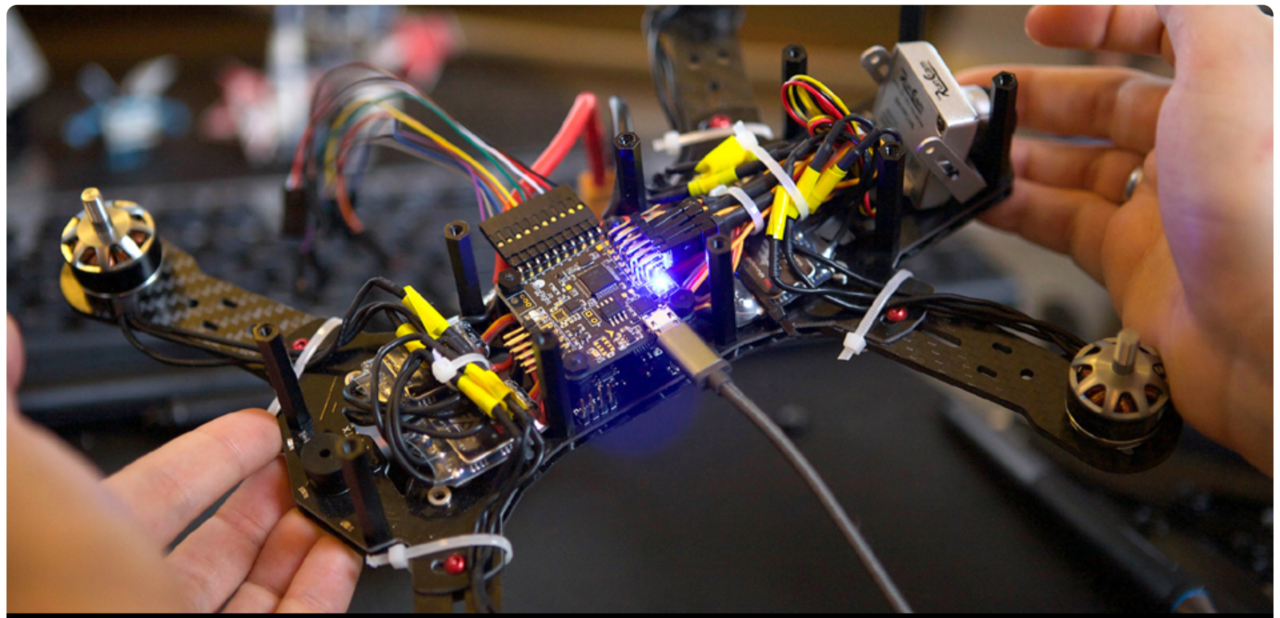

Image: "Drone Building" by Juhan Sonin is licensed under CC BY 2.0

more cost-effective and straightforward for public use than typical UAS designs.

How it's making science more open

The UAS Endurance Challenge is one of many initiatives that seek to cost-effectively manufacture new technology to address an agency research area through collaboration with the public. The competition increases collaboration among NIST employees, engineering students, researchers, and public safety organizations. The competitions also allow participants to better understand the technology involved in government missions, as well as the challenges safety personnel face in the field. Multiple organizations received prize funding which could be used to further develop their technologies, many of which are already commercially available.

Outcome, feedback, and barriers

NIST had success with multiple UAS challenge competitions, including this endurance challenge and a similar indoor UAS challenge. NIST was able to identify and involve new, non-federal innovators in this specific UAS engineering community. In addition, many participants noted gaining more awareness of this agency issue and the challenges public safety members face when deployed on rescue missions. One UAS Challenge participant noted, "it just made me realize even more how much our technology can help you save lives." Over the next few years, NIST plans to further address cybersecurity and device security issues and further research to support public safety communications (B-43) (OSTP, 2022a).

Sub-Surface Automated Dual Water Sampler (NOAA)

VISIT WEBSITE

Communities / agencies involved:

- The Acidification, Climate, and Coral Reef Ecosystems Team (ACCRETE) at NOAA's and Atlantic Oceanographic and Meteorological Lab
- ACCRETE researchers Dr. Ian Enochs and Nate Formel
- Ocean and Atmospheric Research (OAR)

Overview

The SAS was designed by researchers at National Ocean and Atmospheric Administration (NOAA)'s AOML and the University of Miami as a low-cost, open source automated water sampler to help scientists study water chemistry in shallow reef habitats.

How and when was it developed?

In 2018, NOAA awarded ACCRETE researcher Dr. Ian Enochs an Ocean Technology Development grant to design and build a water sampler to help further NOAA's shallow reef research. The team developed the automated sampler after realizing a need to collect data at times when marine conditions were too dangerous, expensive, or impossible to deploy researchers to coral reefs. After receiving the NOAA OAR grant, several NOAA ACCRETE researchers carried out an engineering design process in collaboration with NOAA's Advanced Manufacturing and Design Lab. The open-source community inspired the project platform, which included digital modeling and several prototype designs. Although the water sampler was tested in an advanced wet lab system and the field, the open source design allowed the product to be further refined by the public to meet changing user and researcher needs.

What is it?

The SAS is a water sampler system that is much more accessible and lower cost than other water sampler systems in the market. It costs around $215 and the technology has been constructed by a range of users including school groups, non-profits, and individuals. To support the open source design of the sampler, the ACCRETE team created a website, as well as easy-to-use construction and operating guides. In addition, the team created educational lesson plans and presentations so the sampler may be used in a project-based learning curriculum. The tool was designed from the perspective of a user who does not have a background in engineering or CAD design, but rather an interest in tinkering and using available resources to figure it out.

How it's making science more open

Ocean acidification due to rapidly rising atmospheric CO_2 levels has been occurring faster than at any time in the last 300 million years (Hönisch et al., 2012). Ocean acidification trends in shallow marine environments fluctuate rapidly, necessitating more frequent and dynamic water monitoring programs and technologies. The SAS is made to be distributed and used widely, to collect more data on the changing carbonate chemistry of seawater and to further community understanding of and participation in marine science activities. The ACCRETE research team hopes to allow people access to this technology early on in their scientific education, in order to show how approachable and easy to use these tools can be.

"The team is 'excited for people to use it [SAS] not for the intended purpose but to use it to build something that solves their personal problems or personal questions'."

Image: Use A SAS by NOAA is licensed under CC BY-SA 4.0.

Image: Image by NOAA is licensed under CC BY-SA 4.0.

Outcome, feedback, and barriers

Although the technology has reached users from the Philippines to Central America, the primary users of the SAS have been academic researchers. Further investment in a larger laboratory would increase the number of tools for distribution and could expand the project's reach as a citizen science initiative. However, the SAS initiative has successfully reduced the amount of time and money needed for marine research while ensuring the science is accessible and remains open source. Several projects have evolved from the original SAS and brought in new user groups and applications. A new low-cost, open source technology, a sub-surface automated environmental DNA (eDNA) sampler (SASe), was recently engineered by the same team. The team is "excited for people to use it [SAS] not for the intended purpose but to use it to build something that solves their personal problems or personal questions."

NASA Open Source Build-It-Yourself Rover

VISIT WEBSITE

Communities / agencies involved:

- National Aeronautics and Space Administration Jet Propulsion Laboratory (NASA JPL)
- Students and educators (High school to PhD)
- Robotics-enthusiasts

Overview

The NASA JPL designed an open-source, build-it-yourself version of the 6-wheel rover that NASA uses to explore the surface of Mars.

How and when was it developed?

JPL researchers proposed the open source rover project in 2016 during a NASA innovation pitch day. The project got off the ground in 2017 with the leadership of a JPL project lead, Mik Cox, and two JPL interns. The team completed prototyping and building instructions for the rover in around 10 weeks using the design features of the Mars Exploration Rover, the six-wheel rover that NASA currently deploys to space. Experienced JPL robotic engineers were also consulted during the prototype process. The project was funded and supported by the JPL Technological Innovation and Infusion team, led by one of the projects' key "champions," Tom Soderstrom, JPL's Chief Technology and Innovation Officer.

What is it?

The rover is an open source version of the NASA rovers used to explore Mars. It can be constructed using minimal tools and open source software, providing a hands-on opportunity to understand how space exploration equipment is designed and functions. Although JPL does not provide the parts required for construction, the team

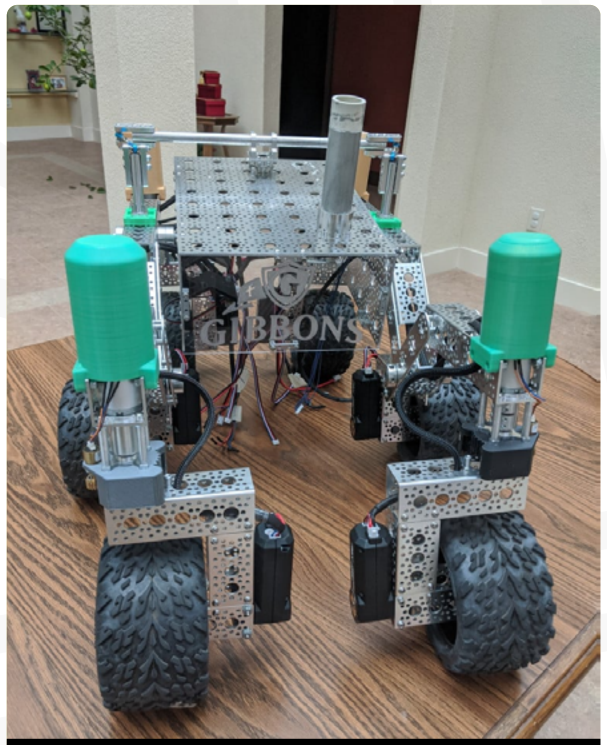

Image: "Trying to make sense of the layout of the Roboclaws and motors" by jtoebes, all rights reserved.

supplies specific instructions and resources for acquiring the necessary rover components. This was one of JPL's first technological endeavors that combined both open source

Image: "rover-climbing.jpg" by Mik Cox is licensed under Apache 2.0 License.

software and hardware. The design plans were made publicly available on GitHub, along with educational resources for high school students up to PhDs. A previous successful educational rover introduced by JPL, called ROV-E, cost over U.S. $30,000. This more recent rover model costs around $2,500 and can be made with commercial off-the-shelf parts.

How it's making science more open

This rover is significantly cheaper than the previous educational rover developed by NASA, which went to museums, schools, and events to get people excited about robotics and space exploration. The construction guides for the JPL Build-It-Yourself Rover are meant to be accessible to students and enthusiasts in high school and up, allowing people to understand the engineering and design process that went into building the rovers currently used in space. The instructions for use are incredibly detailed and the GitHub format allows for collaboration among federal and non-federally affiliated community members. Involvement in this initiative has jumpstarted young scientists' interest in rover engineering and space exploration, such as a third grader creating their own rover-building instructional YouTube videos.

Outcome, feedback, and barriers

In order to test their documentation's accessibility, the team built the robot with multiple high school teams who had no previous robotics experience (Ackerman, 2018). All high school teams were successfully able to build the rover and many more have continued to do so since. In addition, the Open Source Rover project has become a platform for innovation for a diverse range of robotics enthusiasts and students. Since the public release of the rover's open hardware materials,

> **"Project leaders noted the importance of dedicated funding in federal science agencies for small, innovative projects, like those using open source hardware."**

PROPOSAL, DESIGN, OR INITIATION
FUNDING
PRODUCT TESTING AND QUALITY ASSURANCE
TOOL DESIGN
COMMUNITY, RESEARCH OR EDUCATIONAL RESOURCES

enthusiasts have created additional rover features such as a robotic arm and a machine learning-powered rover (NASA JPL Uses Open-Source Technology to Let Enthusiasts Build Their Own Rovers, n.d.). The design and platform for the rover encourage communities to further innovation and generate cost-reducing improvements.

Project leaders noted the importance of dedicated funding in federal science agencies for small, innovative projects, like those using open source hardware. They also emphasized the importance of champions within the federal agency in decision-making roles. These champions provide opportunities for new and innovative ideas, navigating systems and processes meant for proprietary tools, and link the team with different expertise. As of 2022, JPL no longer funds or has staff directly associated with the Open Source Rover project. However, the online Github forum remains active through community use and the models continue to be built by a variety of user groups. In addition, JPL still maintains the Open Source Rover landing page, which receives 80+ views per day.

Image: "In progress build - Clewiston Christian School" by joakingb, all rights reserved.

U.S. EPA Air Sensor Loan Programs

VISIT WEBSITE

Communities / agencies involved:

- United States Environmental Protection Agency (U.S. EPA)
- Tribal governments
- Community organizations, schools, libraries, and museums

Overview

The U.S. EPA has established several programs that bring air sensor technology to the public for monitoring and education. These independently developed programs within this broader initiative have different goals, structures, partners, and funding.

How and when was it developed?

The first Air Sensor Loan Program began in U.S. EPA Region 9 in partnership with the Los Angeles Public Library. U.S. EPA provided the library with air sensors, educational resources, and hands-on lesson plans with the vision that the library would offer community programs and allow members to check out sensors much like they check out books. In 2019, U.S. EPA introduced two more Air Sensor Loan Programs in Regions 5 and 10 to encourage public involvement in measuring air pollution and to help communities understand and explore air pollution problems. These pilot programs include the Demonstration of Air Sensor Loan Programs for Rural Communities and Living/Nature Museums, which provide smaller Midwest communities with sensors to increase awareness of air pollution and its sources and the Demonstration of a Tribal Air Sensor Loan Program, aimed at Pacific Northwest tribal communities that experience air quality decline during wildfire and outdoor burning periods. All three of these pilot programs were funded through U.S. EPA's Office of Research and Development (ORD) Regional/State/Tribal Innovation Project Program. EPA ORD and regional offices provided training and support to get the projects started, but the programs are ultimately administered by partner organizations, such as libraries, schools, and tribes.

Today, Air Sensor Loan programs operate in all 10 U.S. EPA Regions under different funding mechanisms and management, many of which were established using funding made available through the American Rescue Plan Act of 2021 (ARP). These initiatives focus on implementation and expansion, intending to make the loan programs work on a larger scale. The additional Air Sensor Loan programs began launching in 2022 and will further encourage communities to collect and explore local air quality while enhancing knowledge of

Image: "Air Monitoring station, Reno, Nevada" by brewbooks is licensed under CC BY-SA 2.0.

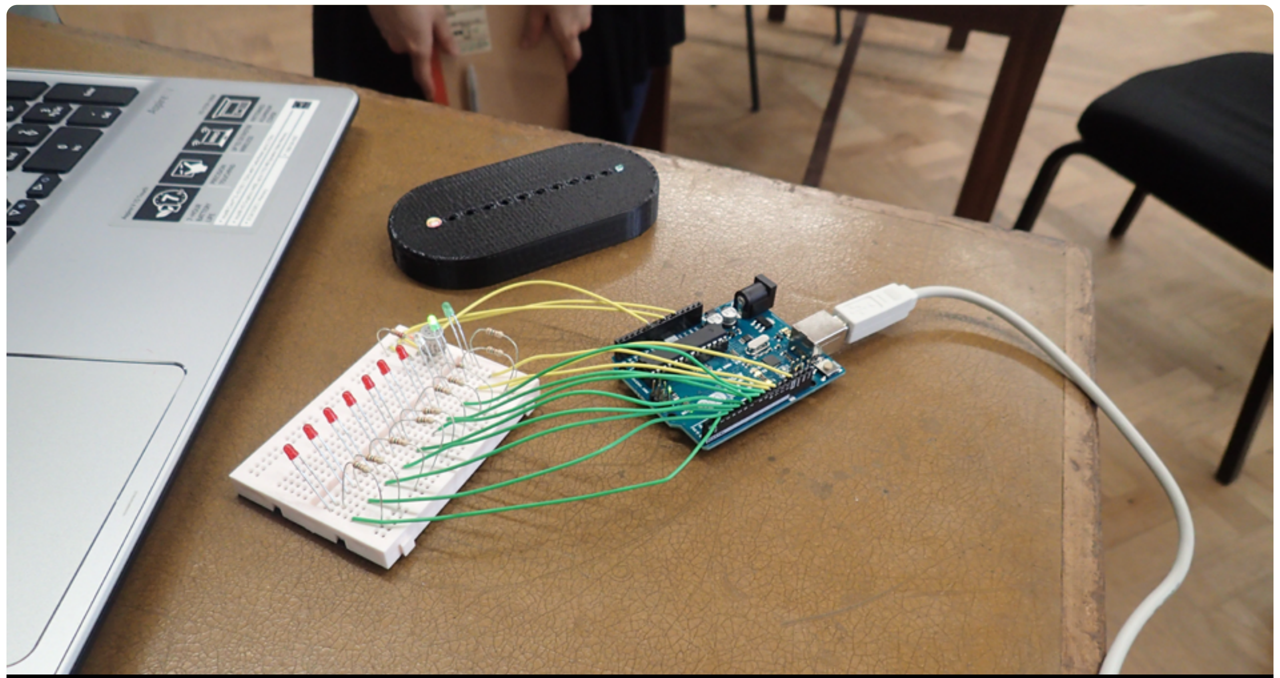

Image: "Air quality monitor - Mini Maker Faire" by Cambridge SynBio is marked with CC0 1.0.

public health and environmental issues.

What is it?

The air sensors available for loan in the program are commercially available, often easy to use, and designed for non-scientists. Many of the sensors cost less than $1,000, significantly less than traditional air monitoring equipment. The U.S. EPA Regional offices use one or more commercially available air sensor models from various manufacturers. All data collected is directly available to the loanees and training on sensor use is provided in most of the programs (by either the U.S. EPA or partners), including troubleshooting and further education.

How it's making science more open

Direct public participation in science and equitable access to newer technologies is the central goal for all of the Air Sensor Loan programs. This includes outreach to underrepresented and underserved populations, youth, remote and rural communities, and communities with environmental justice concerns to increase awareness of air pollution and air monitoring research in a local context. Non-experts can borrow the sensors and are involved in the program implementation, data collection, and educational activities. For the pilot programs in Regions 5, 9, and 10, the U.S. EPA developed extensive educational **resources** for air sensor technology that are available to the public.

Outcome, feedback, and barriers

The Air Sensor Loan Programs in U.S. EPA Regions 5, 9, and 10 were pilot programs,

Image: "Air Quality Monitoring on Sierra National Forest" by Region 5 Photography is licensed under CC BY 2.0.

which led to the creation of a **Best Practices Guide** for creating Air Sensor Loan programs. The information and lessons learned from the demonstration projects were shared by the **U.S. EPA's ORD**. The Best Practices Guide may also serve as a model for other loan programs in federal agencies around the country.

In 2021, the U.S. EPA received over $50 million in ARP funding for enhanced air quality monitoring for communities across the U.S. with environmental and health outcome disparities (U.S. EPA, n.d.). The Inflation Reduction Act of 2022 (IRA) will provide additional funding for communities and the EPA to address air quality concerns throughout the U.S. While these funds will reach beyond the Air Sensor Loan Programs, partnerships between underserved communities and state, tribal, and local governments will continue to be a focus of the U.S. EPA.

NASA CubeSat Launch Initiative

VISIT WEBSITE

Communities / agencies involved:

- National Aeronautics and Space Administration (NASA)
- Universities and educational institutions (museums, non-profits)

Overview

NASA provides CubeSat developers from non-traditional institutions (e.g. schools and non-profits) a lower-cost pathway to experience flight and space technology and conduct scientific investigations.

How and when was it developed?

The CubeSat Launch Initiative was implemented to get young scientists, engineers, and students interested in Science, Technology, Engineering and Mathematics (STEM), and NASA research and space technology development. Every year since 2009, NASA has released a Partnership Opportunity Call to the public, who may submit a CubeSat project proposal. Reviewers are primarily interested in the alignment between NASA's strategic plan, science, and educational components. The accepted CubeSats are paired to a launch mission that studies various space-related phenomena such as solar sails, in-space propulsion, or the earth's atmosphere. In addition, NASA started a prize competition, the Cube Quest Challenge, to get more people involved in CubeSat technologies and missions, specifically for the moon (Lunar Derby) and beyond (Deep Space Derby). NASA oversees the integration of CubeSats with launch missions and the cost of launch, while the CubeSat teams fund their own technology development. During the integration process, NASA researchers work closely with the teams to provide technical assistance and make sure all requirements are met for launch.

What is it?

CubeSats are a class of research spacecraft, called nanosatellites, that are usually 10 cm x 10 cm x 10 cm and weigh less than two kilograms (Science and Technology Innovation Program, 2021). PyCubed and BeaverCube II are just

> **"This is allowing young scientists to break into a rapidly growing commercial industry with a wide user base. In addition, NASA 'strongly encourages CubeSat teams to collaborate with each other' and noted that there is 'lots of camaraderie between CubeSat teams' (Norman Phelps)."**

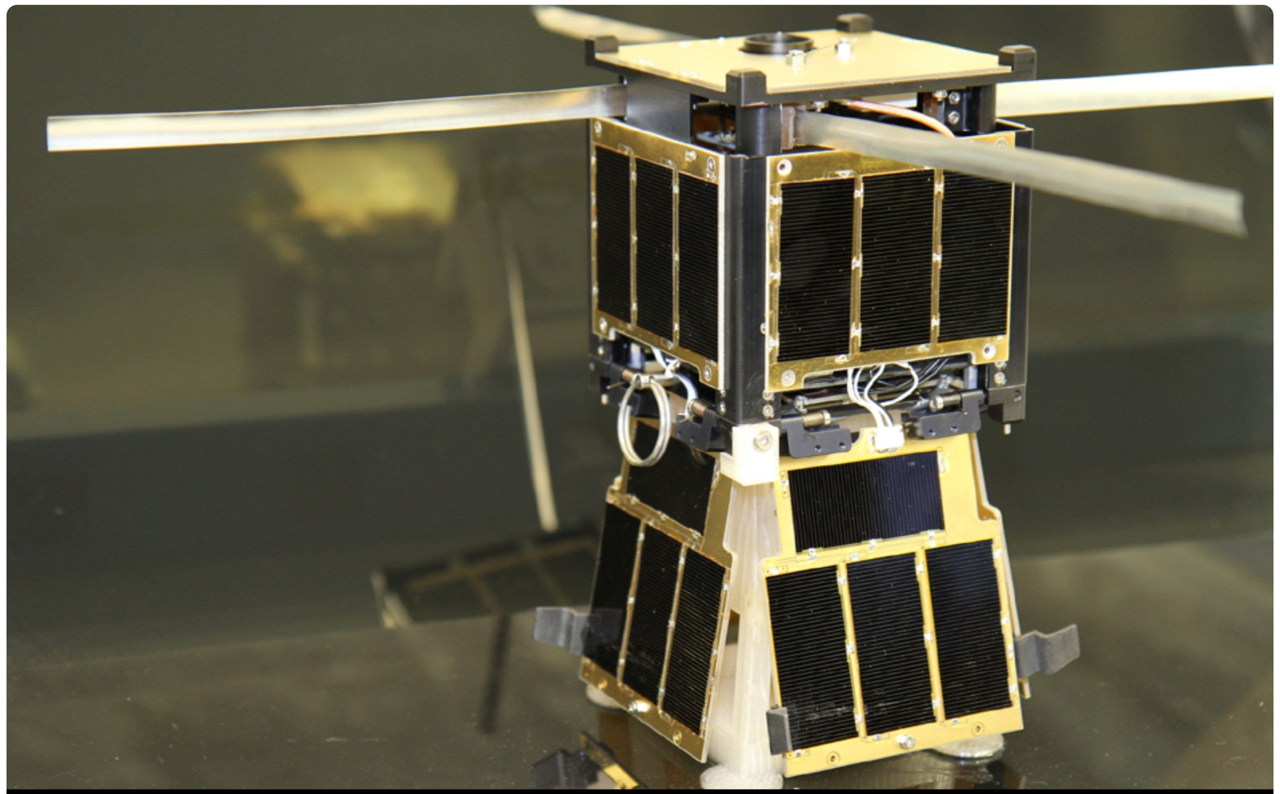

Image: "KySat2 CubeSat - ELaNa IV" by NASA Kennedy is licensed under CC BY-NC-ND 2.0

two of hundreds of partners who are a part of NASA's CubeSat Launch Initiative. PyCubed was designed in 2019 by the Robotics Exploration Lab at Stanford and is an open-source, radiation-tested satellite framework programmable entirely in Python. BeaverCube II is an educational mission that teaches high school students aerospace science by designing a CubeSat. The BeaverCube II is designed to detect cloud properties, ocean color, and properties of earth's climate system. According to an Acta Astrounatuica journal in 2019, of the 46 CubeSat missions launched through this initiative, 87% successfully reached orbit (Crusan & Galicia, 2019).

How it's making science more open

Many of the CubeSats funded by NASA are open source and have educational materials for additional learning and interest. The CubeSats are designed in a variety of settings, most of which involve student and researcher collaboration through an educational institution. In addition, design plans are often made available through the CubeSat project's website to be reproducible and accessible to the public. These missions provide educators with less expensive tools to engage students in satellite design and operation alongside renowned NASA researchers. This is allowing young scientists to break into a rapidly growing commercial industry with a wide user base.

In addition, NASA "strongly encourages CubeSat teams to collaborate with each other" and noted that there is "lots of camaraderie between CubeSat teams" (Norman Phelps).

Outcome, feedback, and barriers

Since its inception, the CubeSat Launch Initiative has launched over 140 CubeSats on more than 40 launch missions. Additional CubeSats are already set to launch in 2023. NASA has continued to grow this program with great success over the last several years, including supporting more CubeSat projects each year, with an emphasis on states who had not yet been involved in a NASA mission. As of August 2022, [20 launches] are scheduled for the next year, including some from traditionally underrepresented universities and states.
In addition, the CubeSat Launch Initiative is testing the capabilities of and expanding the U.S. launch vehicle market. This NASA initiative has spurred immense growth in the CubeSat industry.

"This NASA initiative has spurred immense growth in the CubeSat industry."

NIH 3D

VISIT WEBSITE

Communities / agencies involved:

- National Institutes of Health (NIH)
- Researchers, educators, 3D printing enthusiasts, and medical professionals

Overview

NIH 3D is an open source and interactive platform for finding, downloading, and sharing medically related 3D print files, tutorials, and educational resources. This may include anything from models of cells, proteins, DNA, and human anatomy.

> "This platform and interest group provides free tools that allow anyone to convert blueprints into physical objects in very little time."

How and when was it developed?

NIH 3D was first introduced to the public in 2014 as the NIH 3D Print Exchange at the U.S. Science and Engineering Festival (Coakley et al., 2014). The motivation behind NIH 3D was to create an online database to share the scientific models that NIH has access to, but no way to share publicly and widely. Not only can NIH share the 3D models they have developed, but researchers and individuals working in this space outside of the federal government may also contribute. This platform is the first government-sponsored platform dedicated to 3D printing.

What is it?

The platform hosts over 12,000 medically-related models, publicly available for 3D printing. These models have been developed

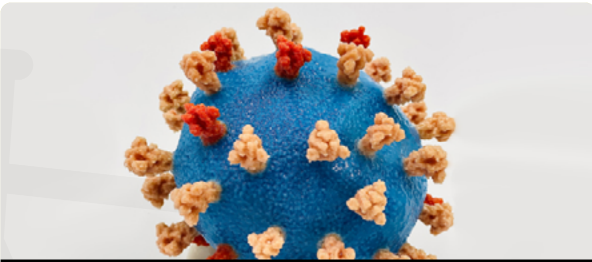

Image: "3D-printed physical model of SARS-CoV-2" by NIH Image Gallery is dedicated to the public domain

by a diverse range of people, including biomedical professionals, researchers, and 3D printing enthusiasts. The platform has five different modules: Discover, Share, Create, Learn, and Engage. Each of these modules serves a different purpose, from providing examples of 3D printing models for download or detailed tutorials on a specific medical application. The website also has tools to convert clinical data to ready-to-print 3D models. The National Institute of Allergy and Infectious Diseases (NIAID) has collaborated with the NIH on cutting-edge medical research, such as printing tangible models of pathogens (NIH, 2014). In light of the COVID-19 pandemic, the NIH 3D has also garnered

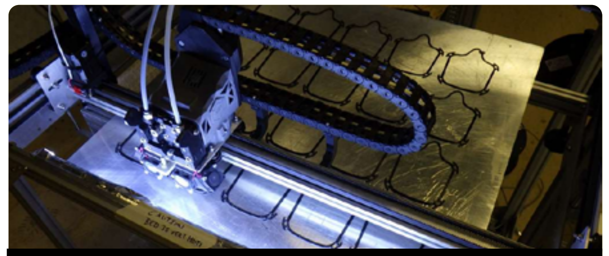

Image: "A 3D printer makes face mask frames on April 10, 2020" from NARA Get Archive is dedicated to the public domain.

increased attention for its ability to support the crowdsourcing the production of personal protective equipment and other critical medical

> "In addition to expanding access to 3D printing resources, NIH 3D has demonstrated the power of having a streamlined platform in the face of national emergencies, such as the COVID-19 pandemic (Science and Technology Innovation Program, 2021)."

equipment and supplies (Bowser et al., 2021; Younoszai, 2022).

How it's making science more open

3D printing is allowing for increased access to science for students, researchers, and the general public. This platform and interest group provides free tools that allow anyone to convert blueprints into physical objects in very little time. NIH has created detailed tutorials to help users use the 3D modeling software to make their own prints. The NIH has also emphasized increasing STEM literacy and education and is promoting the addition of teaching resources and lesson plans in all content posted on the website. This platform uses bioscientific models to bridge the gap between an

> "NIH 3D contributed to a response to supply chain challenges with lower-cost and open tools for public health and safety."

inexperienced user and a 3D modeling expert.

Outcome, feedback, and barriers

Within the first month of release in 2014, the website had received over 11,000 unique viewers (Coakley et al., 2014). In addition to expanding access to 3D printing resources, NIH 3D has demonstrated the power of having a streamlined platform in the face of national emergencies, such as the COVID-19 pandemic (Science and Technology Innovation Program, 2021). In 2020, the NIH 3D created the COVID 3D Trust, a dedicated repository for quick access to a range of 3D printing models of personal protective equipment and medical devices. This was a coordinated effort between the NIH/NIAID, U.S. Food and Drug Administration (FDA), Veterans Affairs(VA), and America Makes. The NIH 3D contributed to a response to supply chain challenges with lower-cost and open tools for public health and safety. In addition, many of these models were tested and vetted for clinical use by the Centers for Disease Control and Prevention (CDC), FDA, or FIOSH standards.

NOAA Technology Partnerships Office

VISIT WEBSITE

Communities / agencies involved:

- National Ocean and Atmospheric Administration (NOAA)
- Small businesses
- Research universities and centers
- Students, educators, and the public

Overview

NOAA's Technology Partnerships Office (TPO) supports the development and commercialization of innovative technologies. The TPO manages both the NOAA Small Business Innovation Research Program (SBIR) and the NOAA Technology Transfer Program (TTP). The Technology Transfer Program ensures that NOAA's publicly-funded innovations are adequately protected and efficiently transferred to commercial applications. The SBIR Program is a grant program that provides seed funding for U.S. small businesses to support technology development across NOAA's mission areas, which include climate, ocean, and satellite research. Both programs work to maximize the benefit of the taxpayer investment in research and development activities at NOAA by encouraging the broadest use possible of any technology that is developed or funded by NOAA. The programs support a strong and resilient U.S. economy.

How and when was it developed?

The SBIR and Technology Transfer programs were mandated under federal law by the Small Business Innovation Development Act of 1982 and the Stevenson-Wydler Act as amended by the Technology Transfer Act of 1986 as well as the Bayh-Dole Act of 1980.

What is it?

Although the Technology Transfer Program and SBIR are common programs in federal agencies, it is unusual for these programs to emphasize open source technologies. Nevertheless, the NOAA Technology Partnerships Office has supported the commercialization and amplification of open source hardware. One of these is the NOAA SBIR-funded effort led by the Wireless Open Water Logger (WOWL) Project. The goal of the project is to increase ocean sampling and data collection by creating a low-cost and open source ocean temperature and depth logger. The WOWL project also aims to integrate data logging with smartphones and share all data freely and openly with the public. Another open-source technology is the Opuhala Sea Temperature Sensor, which was designed by NOAA researchers and partners in 2018. Scientists use this sensor to study the influence of changing sea temperatures on the growth and health of corals around the world while comparing on-the-ground data to satellite data. NOAA emphasized low-cost development to reduce financial barriers and increase public use of this temperature sensor. Other open source technologies can be found on the NOAA Technology Marketplace.

> **"Although the Technology Transfer Program and SBIR are common programs in federal agencies, it is unusual for these programs to emphasize open source technologies."**

How it's making science more open

The NOAA Technology Transfer Program is helping to move NOAA-developed technologies from within NOAA to the public sphere. When NOAA technologies are made commercially available, especially open source and low-cost tools, the technologies can be broadly leveraged by communities, entrepreneurs, and other researchers to fuel further innovation and problem-solving even beyond NOAA's mission areas. The SBIR Program aims to invest in technologies that are not only commercially viable but also have the potential for broad societal impact. For example, one recent funding opportunity invites applicants to propose technologies that facilitate more equitable access to information about extreme weather events. Previous solicitations invited proposals for technologies that support citizen science, which NOAA named as one of six Science and Technology Focus Areas. NOAA's Citizen Science Strategy, released in 2021, highlights the importance of crowdsourced, prize and challenge, and/or citizen science projects to meet changing technological needs and expand public-private partnerships. Finally, the

> **"When NOAA technologies are made commercially available, especially open source and low-cost tools, the technologies can be broadly leveraged by communities, entrepreneurs, and other researchers to fuel further innovation and problem-solving even beyond NOAA's mission areas."**

> **"Beyond working with open licenses and funding low-cost technologies, the Technology Partnerships Office also prioritizes outreach to entrepreneurs and technologists from underrepresented communities to make NOAA's various research-to-commercialization efforts as inclusive and accessible as possible."**

Technology Partnerships Office also broadly seeks to create a more inclusive innovation ecosystem that empowers diverse people to solve problems across NOAA's mission areas. Beyond working with open licenses and funding low-cost technologies, the Technology Partnerships Office also prioritizes outreach to entrepreneurs and technologists from underrepresented communities to make NOAA's various research-to-commercialization efforts as inclusive and accessible as possible.

Outcome, feedback, and barriers

NOAA's SBIR grants and research partnerships have supported the creation and commercialization of easy-to-use technologies, especially for [small businesses] and other research groups that would not typically have as much access to such resources. However, the Technology Partnerships Office faces similar challenges to other federal agencies in aligning open source work with agency legislative authority. The Technology Transfer Program also experiences challenges in ensuring that federal researchers are using open-source licensing in a way that is effectively managed through a transparent technology disclosure and transfer process. Conversely, the SBIR Program operates by providing funds and resources to small businesses and does not actively promote open source technologies. SBIR grants provide funding to support research, development, and commercialization of technologies, and small businesses maintain their own intellectual property throughout this process.

"The Technology Transfer Program also experiences challenges in ensuring that federal researchers are using open-source licensing in a way that is effectively managed through a transparent technology disclosure and transfer process."

Image: Image by NOAA, no known copyright.

NSF Pathways to Enable Open-Source Ecosystems (POSE)

VISIT WEBSITE

Communities / agencies involved:

- National Science Foundation (NSF)

Overview

POSE is a funding program that supports managing organizations that will create and maintain sustainable open source ecosystems around existing open source products.

How and when was it developed?

The solicitation for the POSE program was released in 2022 and is ongoing. NSF had funded the development of open source projects in the past, such as open software for cyberinfrastructure and open data for biological research collections. They noticed that some projects' impacts expanded beyond their original research team to become open-source ecosystems, with an impact across different sectors a large community of users and developers that sustain the project. In order to increase the number of open source projects that have this level of impact, the POSE program was created.

What is it?

NSF has defined "Open-Source Ecosystems" as a "self-sustaining organization that enables the ongoing, distributed, asynchronous development of an open-source product that is designed to be publicly accessible, modifiable, and distributable by anyone under an open-source licensing model." Open source ecosystems have a leadership team that manages and governs development and infrastructure. They have a decentralized network of developers who maintain the product as well as users that provide feedback and insight into the growth of the product. The POSE program has two phases for supporting open source ecosystems: Phase I supports scoping and planning of open source ecosystems and Phase II supports efforts to establish sustainable open source ecosystems.

How it's making science more open

Traditionally, funders have focused on financing the development of open source tools and projects. However, after project development, these projects often lack resources to maintain platforms, communities, further technical development, and scale. The lack of support for open source project maintenance and infrastructure has been a barrier for open science projects reaching their full impact. By funding open science ecosystems, open source projects become more effective at engaging diverse and active participation in science, lowering project costs, and scaling open technology production.

Outcome, feedback, and barriers

So far, NSF invested almost $8 million in the inaugural cohort of 25 Phase I POSE projects. This phase will provide support to discover, organize, and build community around different open science ecosystems. Projects range from creating open science ecosystems to scale renewable energy adoption to supply chain monitoring technology. These projects include open software, data, access, standards, licensing and tech transfer, addressing education, government, and clinical research and supporting products such as hackathons and methodology—with 7 projects including open hardware as a specific component. The POSE

Image: "NIH collaborates with African Academy of Sciences and Bill & Melinda Gates Foundation" by National Institutes of Health (NIH) is marked with Public Domain Mark 1.0.

NASA Transform to Open Science (TOPS)

VISIT WEBSITE

Communities / agencies involved:

- National Aeronautics and Space Administration

Overview

TOPS is a $40 million, five-year NASA initiative aimed to accelerate the adoption and understanding of open science in agencies, organizations, and other scientific communities.

How and when was it developed?

TOPS was developed in 2022 as a part of NASA's Open Source Science Initiative.

What is it?

Over the next five years, the TOPS program will accelerate open science practices through a [series of initiatives](). The program will provide $20,000 in support of Open Science 101, an open science certification developed by NASA. The certification will teach participants how to use digital tools, such as Github, that are commonly used in open science as well as share best practices for data and software management. TOPS also plans to double the participation of historically excluded groups across NASA science as well as enable five major scientific discoveries using open science principles.

How it's making science more open

The TOPS program itself helps make science more inclusive by reducing barriers to practicing open science. It does this by developing a curriculum that introduces scientists to open science practices via its Open Science 101 course and workshops. TOPS also partners with minority-serving institutions to host events and hackathons as well as to recruit for their TOPS internship program. There are also various funding calls targeted to support open science activities in conjunction with the Research Opportunities in Space and Earth Sciences (ROSES) program.

Outcome, feedback, and barriers

This year, TOPS plans to host "Open Science 101" workshops at 12 different professional society meetings as well as help 1,000 sciences gain their open science certificates through their OpenCore curriculum. Each year, they hold an annual hackathon and support three to four interns per year from minority-serving institutions. Furthermore, TOPS plans to pilot open science activities in universities and NASA ROSES-23 program elements.

Image: "2018 USA Science and Engineering Festival (NHQ201804060012)" by NASA HQ PHOTO is licensed under CC BY-NC-ND 2.0

OSTP's 2023 Year of Open Science

VISIT WEBSITE

Communities / agencies involved:

- Office of Science and Technology Policy (OSTP)
- National Science and Technology Council (NSTC) Subcommittee on Open Science
- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)
- National Oceans and Atmospheric Administration (NOAA)
- Center for Disease Control and Prevention (CDC)
- Department of Commerce (DOC)
- Department of Energy (DOE)
- General Services Administration (GSA)
- National Endowment for the Humanities (NEH)
- National Institutes of Health (NIH)
- National Institute of Standards and Technology (NIST)
- Smithsonian Institute (SI)
- United States Department of Agriculture (USDA)
- Commerce, Energy, NASA, and Defense Information (CENDI) interagency group
- Additional agencies adding commitments throughout the year

Overview

On January 11th, 2023, the White House launched a Year of Open Science, with a set of federal agencies to increase the adoption of open science across the federal government. OSTP and NSTC created a definition for open science to be used across the government in addition to spurring a variety of actions by federal agencies. These actions include updating and developing public access plans in light of the updated 2022 OSTP Public Access Memo, creating public resources for open science initiatives, developing open science curriculum, and developing funding opportunities for open science projects, hackathons, and fellowships that bring open science expertise into the federal government.

How and when was it developed?

The Year of Open Science was launched by the Biden Administration's OSTP as a part of the Administration's goals to advance open, equitable, and secure research. In 2022, OSTP updated public access policies in the memorandum "Ensuring Free, Immediate, and Equitable Access to Federally Funded Research" (OSTP, 2022b). The memorandum builds on public access guidance issued in 2013 by ending the optional 12-month embargo for releasing scholarly publications resulting from federally-funded research to the public, making scientific papers and underlying scientific data immediately accessible upon publication. In addition to public access plans, the memorandum guides agencies to improve transparency in authorship, funding, and partnerships. The Year of Open Science comes on the heels of the memorandum's release.

What is it?

The Year of Open Science inspired an initial set of commitments related to open science, including one relating to open source hardware (OSTP, 2023). NSF created a new funding opportunity— the Geosciences Open Science Ecosystem—which supports the sustainability of projects that increase access around "data, physical collections, software, advanced computing, and other resources." Additionally, the NASA TOPS program has developed open source curricula, NOAA plans to launch an Open Hackathon for AI and High-Performance Computing, and many agencies have also updated or released plans related to open access and open data. Other resources include the launch of CENDI's open.science.gov, a website that will release open science announcements, programs, and events to the public.

How it's making science more open

One of the initial accomplishments of the Year of Open Science was the release of an official open science definition by OSTP and NSTC. In addition to highlighting open science as opening the products of research,


Image: "Fall 2010 hackNY Student Hackathon" by hackNY is licensed under CC BY-SA 2.0.

the definition also includes the process of research, allowing the inclusion of practices like open source hardware, citizen science, and crowdsourcing. The definition also provides clarity in the creation of open science, enables interagency collaboration, and makes it easier to promote. The CENDI online resource for open science initiatives helps publicize open science efforts, which can serve as an example for project development or help track impact. Additional efforts help federally-funded research become more accessible as well as build capacity in government for open science.

Outcome, feedback, and barriers

The majority of the commitments focus on open scientific products, such as open access and open data. In addition, the Year of Open Science includes many initiatives that support building open science capacity in government, such as the U.S. Digital Corps' open science impact area and Geosciences Open Science Ecosystem. Finally, the Year of Open Science draws attention and brings credibility to open science, which will help drive the adoption of open science practices across sectors and disciplines.


Image: "geoscience crowd sourcing" by subarcticmike is licensed under CC BY 2.0.

Observations

Through our analysis of and conversations with these government initiatives, we found overarching observations that transect various case studies. These observations provide insight into government perspectives, challenges and barriers, and strategies for success.

The federal government can support tools for open science in many ways

The examples outlined in this report demonstrate the range of ways in which the federal government currently supports tools for open science, from supporting specific open source tools to investing in programs and cross-agency initiatives.

We included case studies with the following types of federal involvement:

Federal funding. Federal grants or funding are forms of financial support from the federal government or agencies for projects, innovations, research, and other public services. They follow a [linear lifecycle] that starts with releasing a funding opportunity, applying, awarding the grant, and then implementing it.

Prize and challenge competitions. Prizes and challenges are competitions rewarded with cash prizes or other incentives. Participants can be individuals or groups from universities, grassroots communities, businesses, non-profits, etc., depending on the competition. In 2010, the [America COMPETES Reauthorization Act] enabled federal agencies to employ prize and challenge competitions to advance innovation related to the agency's mission. Since the passage of this act, prizes and challenges have become more of a common innovation strategy among federal agencies.

Tool created by a federal agency. Federal agencies develop and share a tool. Federal agencies may collaborate with academic institutions, other organizations, or individuals in the design, testing, and other stages of tool development.

Government program or office providing support. Government programs or offices provide physical, digital, technical or legal infrastructure for open science in a project or activity that fulfills their mission.

Initiatives involving multiple federal agencies. Federal stakeholders can collaborate, coordinate, fund, participate in, or support open science government programs.

Open source hardware is not well known and can be misunderstood

Our review demonstrates that often, open source hardware is not well known within the federal government and can be misunderstood, even within institutions supporting open source tools. For example, the NREL mentioned that open source software and open data were commonly discussed in the office, while open source hardware was never mentioned. Similarly, the NASA Open Source Build-It-Yourself Rover team had worked on open source software before, but the project was their first time developing and using open source hardware.

Moreover, although the commercial value of low-cost tools appeared to be broadly recognized and supported, federal projects and programs did not emphasize or appear to recognize commercial value in open source hardware.

Cost accessibility was a principal driver in the creation or support of federal programs

All of the tools, projects, and programs included in our review enable open science through a focus on low-cost tools, broadening accessibility. Going beyond accessibility, our collection of case studies also include nine examples of tools, projects, and programs that used open source and open source hardware specifically, enabling reproducibility and collaboration, in addition to accessibility. Many programs adopted open source as a way to achieve certain goals, like data collection for the Project PANOPTES citizen science project, or STEM outreach in the NASA Cubesat Launch Initiative. Other programs were developed to specifically harvest open source's benefits, such NASA's Build-It-Yourself Rover and NOAA's SAS.

Champions of open science in leadership positions play a key role in these programs

Many programs had champions advocating for their program to come to fruition. In its early stages, the NASA Open Source Build-It-Yourself Rover benefitted from a "champion" in a leadership position, who was key to ensuring initial support and navigating federal processes that were not designed for open source projects.

The NASA TOPS program also recognizes champions as a key infrastructural component of open science. As part of the Year of Open Science, they plan to partner with professional societies to develop open science awards, incentivizing and recognizing champions.

Dedicated funding in federal science agencies for small, innovative projects has a large impact

Federal funding for small, innovative projects had large impacts in terms of both engaging new audiences and the number of people reached by these tools. Foldscope, which was supported by NIH at multiple stages of development, has now distributed over 1.7 million foldscopes, with plans to distribute a million more. Following support for a pilot program from an internal competition for seed funding, the U.S. EPA Air Sensor Loan Programs have expanded to successfully engage underrepresented and underserved populations in air quality monitoring in all 10 EPA regions in the U.S.

These programs have also had an impact in terms of convening community and spurring innovation. Despite a lack of institutional support or funding, Project PANOPTES's community still remains active on its forum. NOAA's SAS has been used by various academic researchers and several new projects have evolved from the tool.

Sustainability for many of these programs was a major challenge

Despite the value of dedicated seed funding, federal support for many of these projects had a finite timeline. This leads to challenges in the long-term sustainability and maintenance of the projects, even with demonstrated value.

In prize and challenge competitions, agencies and other administrators of competitions had very limited involvement post-challenge, making it difficult to assess long-term success and document any applications of the technologies. For example, the U.S. DOE Solar Desalination Prize spurred continued collaboration and commercialization for some of the teams post-competition, but others never fully developed the promised technologies.

Other programs, such as Project PANOPTES and the Open Source Build-It-Yourself Rover, experienced an end to federal funding, saw institutional homes or support staff decrease their involvement over time, and are now maintained almost entirely through community support. Other programs' online presence, such as resources and tutorials, are not regularly updated, indicating a lack of long-term maintenance.

Programs were often categorized under one part of open science, however, recent government initiatives take an ecosystem approach

Despite the value of an ecosystem approach to open science, many government initiatives focus on one specific tool or practice. For example, prize and challenge competitions, such as the U.S. DOE Solar Desalination Prize and First Responder UAS Endurance Challenge, employed open innovation and emphasized accessibility, but did not prioritize open source hardware.

Recent projects and programs are taking a more expansive view. Many projects use open access platforms in addition to their open tools. Programs like the NASA CubeSat Launch Initiative bring in elements of open innovation, open access, open source hardware, and open source software. Recent open science initiatives take an ecosystem approach, especially when providing infrastructural support to open science. NSF POSE funds projects that help increase the sustainability of open science projects, ranging from open hardware to open educational resources; proposals normally include multiple related practices. The OSTP's Year of Open Science does both, by emphasizing an expansive definition of open science but also focusing so far on practices that open the products of science, with less attention to the scientific process. Actions so far have aimed to improve open science infrastructure, such as updating the nation's open access and open data policies and creating a federal open science website.

Conclusion

The 13 case studies in this publication highlight a range of ways that the U.S. federal government advances initiatives supporting tools for open science. Federal involvement ranges from funding tools, programs, and initiatives; providing infrastructure and support; maintaining partnerships and collaborations; and even creating or using open tools internally. Broadly, there is an emphasis on low-cost tools for accessibility, but there is also support for open source data, software, or hardware for collaboration, innovation, and education. Other programs were created with openness as the primary goal. Independent from why open source was used, open source hardware is not a familiar concept in the federal government, especially compared to other open science practices.

In these examples, federal involvement accelerates the impact of tools for open science. These programs helped spur the innovation of new tools for agency-specific or societal needs, provide technical, digital, and physical infrastructure for building new tools, and scale production or the distribution of educational resources around tools. Furthermore, the involvement of federal agencies gives legitimacy to grassroots projects.

The case studies included here represent a range of federal support, from funding for individual tools and approaches, to programs supporting new infrastructure for open science at a large scale. Recent government initiatives, like OSTP's Year of Open Science, NASA TOPS, and NSF POSE are strong first steps toward providing financial, digital, technical, and legal infrastructure for sustaining open science. More and more, the federal government is taking an ecosystem view, by considering tools in the context of open science broadly. This is a trend that can continue with increased education and awareness of the elements of open source hardware and the importance of tools for open science

Conclusion

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References

Ackerman, E. (2018, August 7). NASA's Jet Propulsion Lab has adapted a Mars rover design into something that you can build in your garage. *IEEE Spectrum.* **https://spectrum.ieee.org/explore-new-worlds-with-jpls-open-source-rover**

Bowser, A. Long, A., Novak, A., Parker, A. & Weinberg, M. (2021). Stiching Together a Solution: Lessons from the Open Source Hardware Response to COVID-19. *The Woodrow Wilson International Center for Scholars*. https://www.wilsoncenter.org/sites/default/files/media/uploads/documents/WWICS%20STIP%20Lessons%20from%20the%20Open%20Source%20Hardware%20Response%20to%20COVID-19.pdf

Chesbrough, H. (2006). Open innovation: a new paradigm for understanding industrial innovation. ***Open innovation: Researching a new paradigm***, 400, 0-19.
Citizen Science Association. (n.d.). *The power of citizen science*. CitizenScience.Org. https://citizenscience.org/

Coakley, M. F., Hurt, D. E., Weber, N., Mtingwa, M., Fincher, E. C., Alekseyev, V., ... & Huyen, Y. (2014). The NIH 3D print exchange: a public resource for bioscientific and biomedical 3D prints. *3D Printing and Additive Manufacturing, 1*(3), 137-140. https://doi.org/10.1089%2F3dp.2014.1503

Cohen, S. (2014, March 31). Stanford research develop low-cost paper microscope. *The Standford Daily*. https://stanforddaily.com/2014/03/31/stanford-researchers-develop-low-cost-paper-microscope/

Crusan, J., & Galica, C. (2019). NASA's CubeSat Launch Initiative: Enabling broad access to space. *Acta Astronautica, 157*, 51-60. https://doi.org/10.1016/j.actaastro.2018.08.048

Cybulski, J. S., Clements, J., & Prakash, M. (2014). Foldscope: origami-based paper microscope. PloS one, 9(6), e98781. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0098781

Data Europa EU. (n.d.). *What is open data?* Europa EU. https://data.europa.eu/elearning/en/module1/#/id/co-01

Foldscope Instruments. (n.d.). *Translations*. Foldscope Instruments. https://foldscope.com/pages/translations

Gee, W.T., Schwab, C., Coutts, D., Guyon, O., & Walawender, J. (2018). Project PANOPTES: the good, the bad, and the ugly challenges of running a successful Pro-Am astronomy project (Conference Presentation). *Proceedings Software and Cyberinfrastructure for Astronomy, 1070*(5). https://doi.org/10.1117/12.2314317

Guyon, O., Walawender, J., & Butterfield, M. (n.d.). *Panoptic Astronomical Networked OPtical observatory for Transiting Exoplanets Survey*

(PANOPTES). Project PANOPTES. https://nightsky.jpl.nasa.gov/docs/PANOPTES.pdf

Häuer, M. (2021, January 13). *Open Source Science: Public Money, Public Hardware*. Journal of Open HW. https://journalopenhw.medium.com/open-source-science-public-money-public-hardware-da69c71d8232

Hill, A. (2021, January 15). *Open hardware provides a better chance for scientific reproducibility*. Journal of Open HW. https://journalopenhw.medium.com/open-hardware-provides-a-better-chance-for-scientific-reproducibility-829ed23bb71d

Hönisch, B., Ridgwell, A., Schmidt, D. N., Thomas, E., Gibbs, S. J., Sluijs, A., ... & Williams, B. (2012). The geological record of ocean acidification. *Science, 335*(6072), 1058-1063. https://doi.org/10.1126/science.1208277

NASA JPL Uses Open-Source Technology to Let Enthusiasts Build Their Own Rovers. (n.d.). *Wired*. https://www.wired.com/wiredinsider/2019/09/nasa-jpl-uses-open-source-technology-let-enthusiasts-build-rovers/

National Institutes of Health (NIH). (2014, June 18). NIH launches 3D print exchange for researchers, students. *National Institues of Health: News Releases*. https://www.nih.gov/news-events/news-releases/nih-launches-3d-print-exchange-researchers-students

Office of Science & Technology Policy (OSTP). (2022a). Implementation of Federal Prize and Citizen Science Authority: Fiscal Years 2019-20. *The White House*. https://www.whitehouse.gov/wp-content/uploads/2022/05/05-2022-Implementation-of-Federal-Prize-and-Citizen-Science-Authority.pdf

Office of Science & Technology Policy (OSTP). (2022b). Ensuring Free, Immediate, and Equitable Access to Federally Funded Research. https://www.whitehouse.gov/wp-content/uploads/2022/08/08-2022-OSTP-Public-Access-Memo.pdf

Office of Science & Technology Policy (OSTP). (2023, January 11). *FACT SHEET: Biden- Harris Administration Announces New Actions to Advance Open and Equitable Research*. The White House. https://www.whitehouse.gov/ostp/news-updates/2023/01/11/fact-sheet-biden-harris-administration-announces-new-actions-to-advance-open-and-equitable-research/

Open access.nl. (n.d.). *What is open access?* Open access.nl. https://www.openaccess.nl/en/what-is-open-access

Open Source Hardware Association (OSHWA). (n.d.). Definition (English). *Open Source Hardware Association*. https://www.oshwa.org/definition/

Open Source Initiative. (n.d.). *The Open Source Definition*. Open Source Initiative. https://opensource.org/osd/

Parker, A. & Novak, A. (2020). Building Blocks for Better Science: Case Studies in Low-Cost and Open Tools for Science. *The Woodrow Wilson International Center for Scholars*. https://www.wilsoncenter.org/publication/building-blocks-better-science-case-studies-low-cost-and-open-tools-science

Science and Technology Innovation Program. (2021). *Open Sourced Science: Open Source Space Wars* [Infographic]. Woodrow Wilson International Center for Scholars. https://www.wilsoncenter.org/open-sourced-science/stories/open-source-space-wars/

Science and Technology Innovation Program. (2021). *Open Sourced Science: 3D Printing for Distributed Crisis Response* [Infographic]. Woodrow Wilson International Center for Scholars. https://www.wilsoncenter.org/open-sourced-science/stories/3d-printing/

The Golden Goose Award. (2022). *Celebrating Scientific Success Stories: The Golden Goose Award*. The Golden Goose Award. https://www.goldengooseaward.org/

U.S. Environmental Protection Agency (EPA). (n.d.) *ARP Enhanced Air Quality Monitoring for Communities - Competitive Grant*. U.S. Environmental Protection Agency. https://www.epa.gov/arp/arp-enhanced-air-quality-monitoring-communities-competitive-grant

Younoszai, Z. (2022, July 27). 3D Printing Can Strengthen America's Medical Supply Chain. *Pew Trusts*. https://www.pewtrusts.org/en/research-and-analysis/articles/2022/07/27/3d-printing-can-strengthen-americas-medical-supply-chain

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