Democratized Scientific Instrumentation: Leveraging the Maker Movement

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Democratized Scientific Instrumentation: Leveraging the Maker Movement

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SUMMARY
In today's increasingly connected world, scientists, engineers, entrepreneurs, and citizen inventors are designing, building, and sharing tools in exciting ways. From 3D-printed interactive sensors to do-it-yourself (DIY) underwater robots, the case study highlights in this paper point to a diverse range of applications where the Maker Movement is facilitating hands-on, hardware-based contributions to science and new avenues for public participation.

The grassroots momentum at the confluence of citizen science and the Maker Movement represents a unique and compelling opportunity to launch force-multiplying collaborations and to accelerate advances in science and technology. In particular, the United States Government and other stakeholders can help foster not only valuable *innovations*, but also a diverse coalition of engaged *innovators* who are ready to tackle society's pressing challenges.

This paper discusses stakeholder roles and models of engagement that can improve the citizen science and maker ecosystem, noting design and policy issues that require discussion and coordinated action. For example, *how might government interface with nonprofit organizations, academia, industry, and individual contributors, with each stakeholder bound to different guidelines and constraints? How might communities effectively implement and maintain solutions from informal volunteers and constantly-evolving open source designs?* By taking a cue from the ingenuity and resourcefulness of makers and doers, the U.S. Government can creatively pave the way for sustained science and technology innovation and meaningful engagement.

INTRODUCTION
From an experienced robotics engineer to a young child exploring the "sandbox" of science and technology for the first time, inspired individuals and communities are redefining our perspectives on scientific instrumentation. Today, scientific measurements are no longer limited to laboratories with formally trained experts and complex, costly infrastructure.

The democratization of scientific instrumentation—whether by a reduction in cost, a greater proliferation of distribution networks to improve accessibility, or efforts to make systems more user-friendly—empowers new innovators to contribute their talents. In this paper, democratized science

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instrumentation refers to tools that measure, monitor, or control a process. Numerous examples of software-based tools and analysis (from bird monitoring to 3D brain mapping) continue to demonstrate the value and impact of citizen science. By focusing on physical, hardware-based contributions in this paper, the scope of projects discussed underscores the compelling intersection of citizen science and the Maker Movement.

In the 2013 Second Open Government National Action Plan, President Obama called on agencies to harness the ingenuity of the public by accelerating and scaling the use of open innovation methods such as citizen science. Indeed, through citizen engagement, millions of volunteers across the Nation contribute their time and expertise to help advance shared scientific and societal goals. For example, in January 2015, researchers quantified the scale of biodiversity citizen science, noting for 388 projects, ~1.3 million volunteers made in-kind contributions of up to $2.5 billion USD annually.

In a similar vein, the last decade has increased the visibility of the Maker Movement that connects the estimated 135 million Americans who are makers, celebrating resourcefulness, tinkering, and invention with growing fervor. Across the globe, makerspaces, maker classes, and a growing network of maker mentors are accelerating the learning and building process, enabling tangible innovations with new possibilities for improved accessibility and engagement.

This past year, the first DC Mini Maker Faire in the Nation's capital brought together 22 Federal agencies and departments, along with representatives from the District of Columbia Mayor's Office, the Congressional Maker Caucus, the White House Office of Science and Technology Policy, and over 3,000 maker enthusiasts. The same month, a Presidential Proclamation for a National Day of Making encouraged Americans to bring their ideas to fruition through the "next great technological revolution" and a renaissance in American manufacturing. The first White House Maker Faire held on June 18, 2014, the National Day of Making, included an extensive collection of commitments made by Federal agencies, libraries, the private sector, more than 90 mayors, and more than 150 colleges and universities reaching over 3 million students.

This ever-expanding reach of the Maker Movement and citizen science, combined with a rapid pace of invention and iteration, calls for a dynamic, constantly updated curation of projects. The selected case study highlights below capture project objectives, leading practices, and overarching themes with the purpose of inspiring new and sustainable ways for the Federal Government and other stakeholders to foster, amplify, and broaden access to citizen contributions.

CASE STUDY HIGHLIGHTS: EMPOWERING SCIENCE AND TECHNOLOGY CONTRIBUTIONS

1. USAID, CDC, DOD, White House Look to Maker Movement for Ebola Grand Challenge

Photos: U.S. Agency for International Development

The U.S. Agency for International Development (USAID) partnered with the Centers for Disease Control and Prevention (CDC), the U.S. Department of Defense (DOD) and the White House Office of Science and Technology Policy to convene non-traditional solvers for a mission-critical challenge—as the crisis was happening. The *Fighting Ebola: A Grand Challenge for Development* efforts were launched to help contain Ebola and to develop potential solutions that could help health care workers provide better care for patients in the field.

While USAID has managed a handful of other grand challenges since 2011, this was the first that reached out to makers so explicitly at a time when the United States was actively on the front lines of the worst Ebola epidemic on record. Notably, the first part of the initiative leveraged the OpenIDEO interactive, human-centered design approach to brainstorm, collaborate, and comment on ideas. The urgency and focus on practical solutions was underscored by USAID's aim to begin funding ideas just weeks after the call to action. Hence, an in-person brainstorming session with over 100 engineers, makers, sensor experts, manufacturers, and scientists was immediately followed by prototyping at a local makerspace to allow participants to think more deeply about their concepts as they built "version 1.0" solutions.

Over 1,500 potential solutions were gathered in the competition for $5 million USD, and 15 innovations were identified for support. Low-cost hardware-based prototypes included wearable patient sensors (a disposable, Bluetooth-enabled "Band-Aid" sensor for measuring vital signs such as a patient's heart rate, respiratory rate, temperature, and oxygen saturation) and a battery-powered infusion monitor to help regulate patient hydration.

To help encourage sustainable and open solutions, the program organizers developed a website capturing the problem scope, descriptions and photos of the prototypes, and insights about the human-centered design process that can be extended to other challenges. With a "Get Inspired" portal that includes a look at design questions about solution feasibility, scalability, and other metrics, the effort sets an example for the use of collaborative, human-centered innovation processes and champions the power of rapid prototyping in interdisciplinary teams.

2. DHS S&T, FEMA, Intel, The Feast, IDEO Host Hardware Hackathon for Disaster Preparedness

Photos: U.S. Department of Homeland Security

In October 2014, the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T), Federal Emergency Management Agency (FEMA), Intel, and IDEO collaborated with the nonprofit group The Feast to host a Civic Hardware Hackathon for Disaster Preparedness. Like the *Fighting Ebola* case study mentioned above, this effort also reached out to non-traditional solvers for a mission-critical challenge, but "at steady state," during the long tail of recovery from Hurricane Sandy.

By hosting the hackathon in Red Hook, Brooklyn, a neighborhood that was hit particularly hard by Hurricane Sandy and is still rebuilding, the organizers were able to connect the technologists, makers, entrepreneurs, U.S. Government, and innovation mentors with disaster survivors and local emergency responders who represented the end-users for many of the technologies being developed. The program emphasized a hands-on introduction to human-centered design, rapid prototyping, and the value of low-cost, grassroots resourcefulness throughout the event. Participants were encouraged to share open source code and open source hardware designs, and to use the online portal disasters.data.gov as a means for hackathon participants to stay engaged with the interagency initiative.

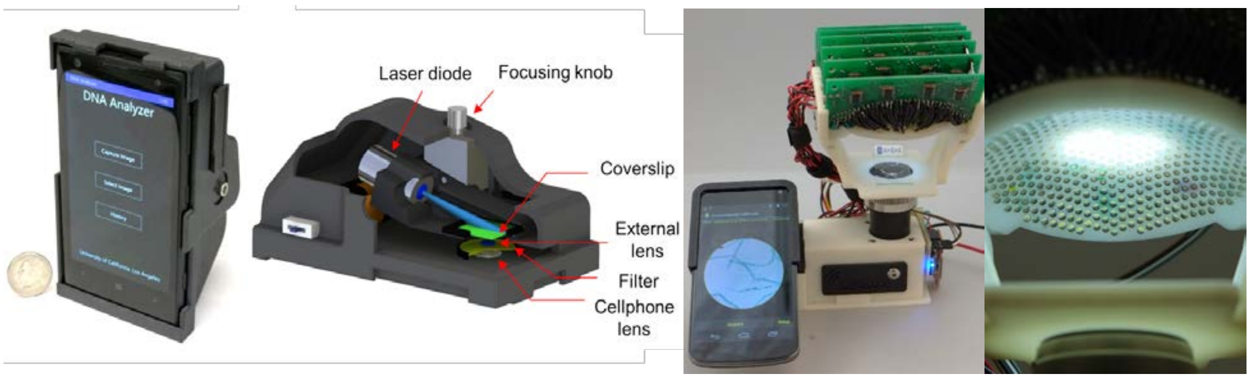
The Civic Hardware Hackathon results included these highlights:

- Eskuwela Now built a "pop up" classroom in a shoebox to help students and families return to their school routines after a disaster. The project team created a multi-touch smartboard with a Wii remote, projector, infrared pen, and a Raspberry Pi device, allowing educators and communities to set up a classroom for 10% of the cost of a typical smartboard.
- HeatSeekNYC aimed to tap into the Internet of Things to diagnose problems in heating systems and empower landlords and tenants to keep the heat on responsibly. The project team leveraged HeatSeekNYC's recent NYC Big Apps and September NY Tech MeetUp progress, creating 14 prototype sensors at the hackathon and collaborating with other teams.
- Civic Ninjas started a new "Citizen Power Brigade" project for the hackathon to transform a hybrid electric vehicle into a clean and fuel-efficient source of mobile emergency power. The prototype charged up to 100 phones simultaneously, and was demonstrated at over 3 locations in Brooklyn during the hackathon. In one week with a single tank of gas, one hybrid car can charge 8,400 phones, providing 12 million minutes of talk time for disaster survivors or providing emergency power to run appliances such as refrigerators. The Civic Ninjas are creating an open source hardware "how to" GitHub guide for the project, incorporating low-cost, commonly-available parts.

For the hackathon, Federal agencies (DHS S&T, FEMA) hosted and planned the event with private sector co-hosts (IDEO, Intel, and the social innovation group The Feast), integrating time for feedback and co-design with the American Red Cross, New York City Office of Emergency Management, and the Red Hook Initiative Community Center. Mentors from DHS S&T, FEMA, the U.S. Environmental Protection Agency (EPA), the National Aeronautics and Space Administration (NASA), and the Millennium Challenge Corporation volunteered their time on Friday evening and Saturday, reflecting the extent of U.S. Government interest in the effort.

By having the subject-matter experts and programming contributions from the U.S. Government, and the funding and in-kind sponsorship coordinated by a nonprofit organization in conjunction with a co-located conference, the collaboration leveraged each stakeholder's capabilities to increase the impact. Moreover, The Rockefeller Foundation sponsored a digital project platform to enable continued collaboration, allowing participants to share ideas, code, data, and open source hardware designs after the hackathon.

3. Cell Phones and 3D printing Help Advance Low-Cost Biomedical Imaging



Photos: UCLA Ozcan Laboratory (left) and UC Berkeley Waller Laboratory (right)

Researchers and civic-minded makers at the University of California at Los Angeles (UCLA) and the University of California at Berkeley (UC Berkeley) are working to dramatically reduce the costs associated with biomedical imaging by leveraging cell phones and emerging fabrication techniques.

- The UCLA California NanoSystems Institute recently reported the development of a mobile microscopy unit consisting of an inexpensive, 3D-printed optical device that uses a phone camera to visualize and measure the length of single-molecule DNA strands. The device features an attachment that creates a high-contrast, dark-field imaging setup using an inexpensive external lens, thin-film interference filters, a miniature dovetail stage, and a laser diode that excites fluorescently labeled DNA molecules. The DNA molecules are stretched on disposable chips that fit into the smartphone attachment, and users can transmit images to a UCLA server for analysis. Funded by the National Science Foundation (NSF), the project aims to use the microscopy units to detect and diagnose cancer, nervous system disorders, and drug resistance in infectious diseases.

- Researchers developing and extending the CellScope project at UC Berkeley are iterating on a new device where the microscope lamp is replaced with an array of light emitting diodes (LEDs) to allow for different imaging approaches. Brightfield, darkfield, phase contrast, super-resolution, or 3D phase imaging are all made possible with the same hardware by designing computational illumination algorithms. The ability to scan through illumination angles to provide 3D light field data and refocus after an image is captured reduces the need for precise mechanical focusing during experiments. The UC Berkeley research team works to share their designs, algorithms, and documentation, aiming to make the entire project open source to be replicated, used, and improved by the community.

In discussing the sustainability and long-term impact of such research, one of the open questions is what pathways might be used to accelerate progress from a proof-of-principle to a robust, massively deployable product. While graduate students complete their projects by pushing the frontier of knowledge, there are often complications with “hardening” university innovations to the point that they can be readily manufactured at scale and widely adopted. By collaborating with technology incubators or extending the “product development” team involved with graduate-level university research to undergraduates, other students, and citizen scientists/makers, researchers can increase the impact of their work and help contribute to experiential education for a large scientific community.

4. Educators Cultivate Interdisciplinary Maker Teams and Foster Experiential Learning

Photos (l-r): Stanford SparkTruck interior and workshop (sparktruck.org), UC Berkeley Paulos Laboratory sensors

In the last few years, numerous maker projects have taken flight organically from educational institutions to spread across the Nation and over digital platforms, cultivating the next generation of maker technologists and citizen scientists.

The educational build-mobile SparkTruck started when a group of Stanford students curious about making, education, and technology pulled over $30,000 USD from a Kickstarter Campaign to fill a truck with maker tools like laser cutters and 3D printers. The team traveled across 33 different states, visited over 2,700 students in more than 70 different locations over the summer of 2012, and partnered with LEGO for another series of build-it-yourself technology workshops in the summer of 2013. Resources developed include an open source “How to Make a SparkTruck” guide, “Tool Cards” that provide a user-friendly introduction to maker tools, templates for hands-on lesson plans, and a documentary movie.

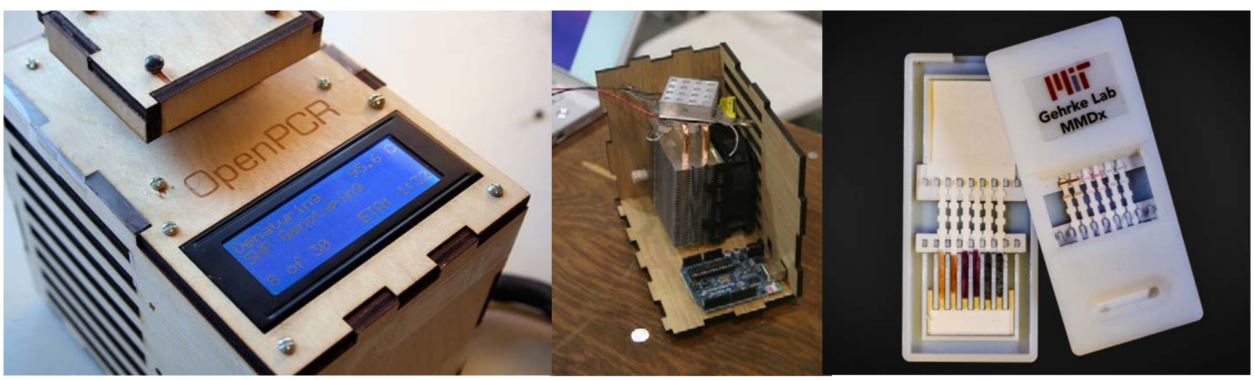
The Hasso Plattner Institute of Design at Stanford (known as “the d.school”) continues to develop experiences in hybrid learning and to engage citizen scientists/makers, with projects like Maker Breaker, a collaboration between the d.school’s K12 Lab Network and the nonprofit organization Breaker. Maker Breaker featured an open 14-day design thinking and entrepreneurship challenge to “Design the Future of Stuff” and explore what making and manufacturing could look like in “an age of distributed creation, mass customization, and globalization.” With online teams as well as in-person teams in facilitated studios, students used video guideposts and curated resources to navigate the innovation process. Professional development “ride-along participants” were given a glimpse into the student problemsolving process, and project teams devised ways to enhance the future of making with products and services that included mechanisms for technologists to more easily adapt products to be sold in niche markets across the nation. By co-locating students, visionary leaders, manufacturers, designers, and entrepreneurs, the effort facilitated mentor networks and a learn-as-we-go ethos.

In a similar manner, the UC Berkeley Invention Lab, which became operational in 2012, serves as a makerspace and innovation hub that fosters hands-on learning and citizen engagement. Open to UC Berkeley affiliates and students, with "inventioneer" assistants providing guidance on how to use prototyping tools, the facility prides itself on recruiting students outside of engineering and science, attracting art students and other innovators for a broad range of project application areas.

Projects like MetaMorphe, which allows for 3D printing of passive components like resistors, capacitors, and inductors, as well as ways to bring a model to life with embedded data, can push the frontiers of interactive and responsive technology. For example, a pair of 3D-printed "smart sunglasses" could have embedded data about local weather patterns and allow for unprecedented real-time control and measurement feedback cycles for a seamless user experience. As wearable technologies and interactive fashion gain momentum, students are experimenting with textiles, stickers, temporary tattoos, and "cosmetic computing" where new materials sense and respond to stimuli. These low-cost devices, as shown in the UC Berkeley Skintillate tattoo sensors project image above, have the potential to transform the everyday consumer into a citizen scientist. Only 38 microns thick, these "epidermal electronics" bring new levels of flexibility and customization into the forefront of citizen science and making.

Furthermore, youth-oriented citizen science and maker initiatives like the Brooklyn Robot Foundry, the Sensory Triptych project, and the Community Science Workshop (which focuses on underserved communities), enable children to contribute to scientific discovery with low-budget hardware and to envision themselves as the research scientists and engineers of tomorrow.

5. OpenPCR and Little Devices Lab Increase Access to Hardware and Scientific Protocols



Photos: OpenPCR.org (left, center) and MIT Little Devices Lab (right)

Maker projects that drastically reduce the barriers to entry for biomedical diagnostics and health research often include participation from grassroots, DIY online communities as well as from members of institutional makerspaces. Accessible hardware as well as documented scientific protocols and processes are critical to the development of citizen science projects in this field.

Examples of projects that work towards low-cost biomedical measurement and analysis include the OpenPCR project and prototype sensors being developed at the Massachusetts Institute of Technology (MIT) Little Devices Lab:

- The OpenPCR project develops open source hardware, software, and protocols to perform Polymerase Chain Reaction (PCR) for the amplification of DNA. Applications include point-of-care medical diagnostics and food supply analysis. With real-time PCR equipment costing on the order of $30,000 USD, the OpenPCR assemble-yourself kits have reduced the barriers for scientists significantly; ordering a DIY kit costs less than the state tax would for a typical real-time PCR module.

  The project aims to support the DIY biology community beyond lower-cost hardware, providing PCR protocols and assays and sharing insights from practitioners. For example, when Arizona State University integrated OpenPCRs in a biomedical engineering class, students designed and documented ideas for building upon the OpenPCR project, and these suggestions were shared online. As the OpenPCR community matures, lessons learned are captured on community blogposts; recent discussions included the need for a coordinated or centralized entity for physical manufacturing and hardware distribution to provide more reliable sourcing and shipping.

- The Little Devices Lab at MIT strives to empower stakeholders with low-cost, participatory technologies for health. Projects include paper diagnostics that can detect Ebola as well as other viral hemorrhagic fevers in approximately 10 minutes, using nanoparticles of different colors to indicate different diseases.

6. e-NABLE Community Shares Designs, Builds, and Donates Prosthetics Around the World

Photos: enablingthefuture.org

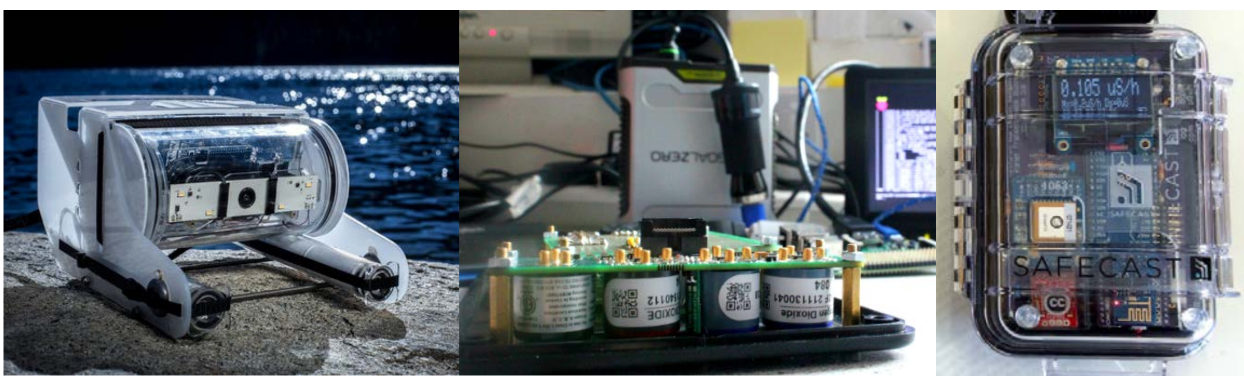
In 2011, a prop-maker from Washington state and carpenter in South Africa came together to create a prosthetic hand device for a small child, and then gave the design away for free to enable others to make hands for themselves and others. The e-NABLE community now includes K-12 students, occupational therapists, designers, artists, roboticists, physicians, prosthetic recipients, and other volunteers inspired to build, teach, and guide each other in giving the world a "helping hand."

Jon Schull, founder of the e-NABLE community, worked with pro bono attorneys and an informal strategic planning committee to create a nonprofit corporation. The Enable Community Foundation serves to support e-NABLE operations, research and development, outreach, education, and training, with fiscal sponsorship from the Fab Foundation. The Enable Community Foundation's mission is to enable anyone to receive free or very low-cost experimental upper limb prosthetics. The Enable Community Foundation also strives to openly share research and development progress, and to create an online community of digital humanitarians.

A professionally made, muscle-actuated hand can cost up to $10,000 USD, with most of the cost stemming from the parts. In comparison, a Raptor hand, one of the most recent prosthetic designs from e-NABLE, has 3D printed parts amounting to approximately $35 USD. In 2014, the e-NABLE community created more than 700 hands and grew from 200 to over 3,200 members. During the year, the designs expanded from one basic blueprint to over 10 new designs for wrist-driven hands, arms, exo-skeletons and even feet and legs. The community also hosted its first Prosthetists Meets Printers conference with over 400 participants, including prosthetists, medical professionals, families, occupational therapists, U.S. Food and Drug Administration (FDA) representatives, and surgeons. With a Google+ community of over 4,000 members, e-NABLE estimates that 1,000 hands have been delivered to date.

In collaboration with e-NABLE, the U.S. Veterans Administration (VA) launched an Innovation Creation Series in May 2015 to crowdsource prosthetic and assistive technologies. With the series, the VA Center for Innovation aims to accelerate the development of personalized services and technologies to improve the care and quality of life for Veterans faced with disabilities. The program is creating an open repository of designs, demonstrating the value of rapid prototyping and co-creation, and leveraging existing online innovation platforms from NASA. After a kick-off event timed with the 10th annual Bay Area Maker Faire, a "pop up box" innovation space has traveled across the country with live make-a-thons and opportunities to spread awareness about the online design challenge.

7. Numerous Environmental Monitoring Efforts Engage Citizen Scientists/Makers



Photos: OpenROV (openrov.com), Citizen Sense (citizensense.net), Safecast (safecast.org)

Communities engaged in environmental exploration, sensing, and monitoring, whether for detecting atmospheric pollutants or mapping underwater ecosystems, represent one of the most prolific and long-standing groups of citizen scientists/makers using low-cost scientific instrumentation.

Below are several examples of citizen scientists measuring and monitoring their environment:

- The Public Laboratory for Open Technology and Science (Public Lab) is an open network of community organizers, educators, technologists, and researchers working to create low-cost solutions for monitoring air, water, and land environments. Since its inception in 2010, the community has amassed diverse expertise, collaborating through open discussion lists organized by region and topic, as well as through in-person chapter events. Public Labs' Research Notes allow members to share their work for input, feedback, and documentation. Wiki pages form a collective knowledge base and can be edited by anyone with a publiclab.org account. Finally, the Public Lab Archive hosts open data created by Public Lab citizen science tools. Funding sources for Public Lab have included foundations, the EPA, Kickstarter crowdfunding, and in-kind donations from individuals and the private sector.

- OpenROV is another open source community that leveraged Kickstarter. OpenROV strives to create more accessible and affordable underwater remotely operated vehicles (ROVs) with a global community of DIY ocean explorers who are constantly tinkering with and improving robot designs. The OpenROV project started in a Silicon Valley garage and now sells assembled robots and robot kits that can be built in a weekend. The latest OpenROV v2.7 includes live high-definition video, LED lighting, dual microprocessors, and a payload area for additional hardware and equipment. The community behind OpenROV contributes to online discussion forums, assembly and operation guidelines, and blogposts, as well as self-organized in-person build days, local expeditions, and hack days. With comparable, commercially-available systems costing up to $200,000 USD, the freely-available robot hardware and software designs from OpenROV, coupled with kits costing less than $1,000 USD, open the door for effective crowd-driven innovation. To date, the more than 1,000 members of the OpenROV community represent participation from over 50 countries.
- The Citizen Sense project, which runs from 2013 through 2017, investigates the relationship between technologies and practices of environmental sensing and citizen engagement. Through fieldwork and the study of sensor applications, the project aims to contextualize, question, and expand upon the understandings and possibilities of democratized environmental action through citizen sensing practices. Three main Citizen Sense project areas tackle distinct applications of citizen science and making: (1) "Wild Sensing" focuses on the use of sensors to map and track flora and fauna activity and habitats, (2) "Pollution Sensing" concentrates on the use of sensors to detect environmental disturbances, including air and water pollution, and (3) "Urban Sensing" contributes to urban sustainability or "smart city" projects that implement sensor technologies.

  Citizen Sense teams are developing a kit for monitoring air pollution in relation to fracking infrastructure. The teams are working with off-the-shelf analog technologies and borrowed devices including the Carnegie Mellon University Community Robotics Education And Technology Empowerment (CREATE) Lab Speck air-quality monitor. With a homegrown Citizen Sense kit or "Frackbox," Citizen Sense teams are building a network of sensors in collaboration with community residents at workshops and "walking events" where volunteers install the devices. The Frackbox runs off a Raspberry Pi microcontroller and includes sensors for nitrogen oxide (NO), nitrogen dioxide (NO_2), ozone (O_3), and benzene, toluene, ethylbenzene, and xylenes (BTEX), as well as humidity and temperature. By placing the monitoring kit at sites near fracking infrastructure and in residential areas, the project teams can monitor emissions over several months.
- Safecast is a global project working to empower people with environmental monitoring data, primarily by building a sensor network and mapping radiation measurements. After the 2011 earthquake and resulting nuclear situation at Fukushima Daiichi, Safecast worked with International Medcom, Keio University, The John S. and James L. Knight Foundation, and GlobalGiving to construct a radiation sensor network of static and mobile sensors deployed around Japan. Initially funded via Kickstarter and private donations, Safecast has a small core team and more than 100 regular volunteers who have deployed over 800 sensors that have collected over 28 million data points. The data collected are published openly under Creative Commons licenses.

- EPA's Air Sensor Toolbox for Citizen Scientists provides information and guidance on low-cost, compact technologies for measuring air quality. In collaboration with Federal, state, and non-governmental institutions, the EPA is encouraging the development of new sensor technologies and providing guidance documents for citizen scientists employing existing techniques.

- The Community Collaborative Rain, Hail, and Snow (CoCoRaHS) Network is the largest source of daily precipitation data in the United States, with over 20,000 active volunteers of all ages measuring and investigating precipitation. Citizen scientists use low-cost, high-capacity rain gauges along with rulers and foil-wrapped Styrofoam "hail pads" to measure rain, hail, and snow. CoCoRaHS data are used by a wide variety of organizations, including the National Oceanic and Atmospheric Administration (NOAA) National Weather Service, the National Integrated Drought Information System (NIDIS), the U.S. Department of Agriculture (USDA), private sector and university meteorologists, emergency managers, city utilities, insurance adjusters, and educators.

  CoCoRaHS is just one of over 65 active citizen science projects across NOAA, many of which began within the past few years. To help foster sharing and collaboration amongst the citizen science projects, NOAA has an active Citizen Science Community of Practice and also participates in the Federal Community of Practice for Crowdsourcing and Citizen Science (FCPCCS) that aims to expand and improve the U.S. Government's use of crowdsourcing and citizen science to enhance mission, scientific, and societal outcomes. Recently, as part of the fifth annual White House Science Fair, NOAA's Office of Education partnered with the White House and the National Park Service to install a rain gauge in the First Lady's Kitchen Garden.

- GeoMakers is a free, open community that collaborates to envision, build, and implement open source maker projects that involve mapping, remote sensing, navigating, and understanding our world geographically. The community seeks to change how people see and interact with the world by using inexpensive DIY techniques.

- Ecosynth is an open source suite of tools for mapping and measuring terrestrial ecosystems in three dimensions using off-the-shelf digital cameras and open source computer vision software, from the ground or using low-altitude hobbyist aircraft.

8. Unmanned Aerial Systems Elevate Citizen Scientists' Ability to Contribute Above Land

Photos: Nerds for Nature (nerdsfornature.org), Carbon Origins (carbonorigins.com), NASA

Unmanned aerial systems are becoming more sophisticated, robust, and prevalent, allowing citizen scientists to expand their horizons in air and space. Makers developing and contributing to scientific exploration and measurement in this arena have been associated with informal volunteer organizations, small entrepreneurial teams, and government-sponsored initiatives.

Examples of citizen science and maker projects with unmanned aerial systems include:

- Nerds for Nature is a volunteer organization that convenes environmental professionals, technologists, and designers, first in dialogue and then to collaboratively create new tools to help people discover, protect, and understand the world around them. The group organizes mixers and acts as a MeetUp group, convening hackathons, workshops, and "skillshare sessions" where the community shares skills with others. Nerds for Nature hosted a public drone MeetUp event on Mare Island, a U.S. Geological Survey (USGS) test site, to test small quadcopters equipped with remote sensors for analyzing water quality. Typically, the USGS deploys staff once a month to do manual salinity tests across three states. Drones equipped with remote water sensors could act as nodes in a large wireless network for monitoring coastal ecosystems more efficiently.

- Carbon Origins is a maker team that grew organically from a group of college students who moved to the Mojave Desert, bought a house to serve as a makeshift laboratory, and attempted to launch rockets. Their initial rocket exploded, but the team didn't have a data logger to help determine why. With existing data loggers falling short of the makers' expectations, the Carbon Origins project was born. The latest iteration of the resulting six-layer Apollo board features 11 sensors and a total of over 200 components in less than two square inches—including an accelerometer, gyroscope, magnetometer, and GPS—with the ability to record audio and measure temperature, pressure, humidity, and ultraviolet or infrared light. Bluetooth, onboard wi-fi, and a storage card allow for local data logging, and users will interface with the board via a trackball and an organic LED screen. The board design is completely open source and is currently in pre-production, having been shown at the Maker Faire, Maker Con, and the International Consumer Electronics Show.

- The Synchronized Position Hold, Engage, Reorient, Experimental Satellites (SPHERES) Zero Robotics competition and the AstroPi competition give students a chance to participate in International Space Station (ISS) experiments. SPHERES is a collaboration between NASA, the Defense Advanced Research Projects Agency (DARPA), and MIT that began as a challenge to develop a device similar to the training drone seen in *Star Wars Episode IV: A New Hope*. Prototypes were produced and tested on parabolic flights, using jets of pressurized gas to allow six degrees of freedom in movement. For the SPHERES Zero Robotics competition, teams of middle and high school students were given a challenge which they must overcome by programming the SPHERES satellite, and astronauts ran code from the competition finalists live on board the ISS.

  In a similar vein, the AstroPi competition launched in January 2015 is open to all primary and secondary school students residing in the United Kingdom. The AstroPi Raspberry Pi board includes a gyroscope, accelerometer, and magnetometer, in addition to sensors for temperature, barometric pressure, and humidity. The deployed AstroPi units will have the winning code from the competition loaded in orbit, and the data collected will be downloaded to Earth for distribution to the winning teams. Moreover, the AstroPi competition will be supported by a suite of teaching resources for Science, Technology, Engineering and Math (STEM) learning.

GOVERNMENT SUPPORT FOR MAKERS AND CITIZEN SCIENCE

The U.S. Government has a history of applying the talents, energy, and creativity of citizen scientists to inspire progress and extend scientific frontiers. In fact, the origin of today's National Weather Service can be traced to a crowdsourcing project in the mid-1800s led by the Smithsonian Institution: volunteers providing weather observations to Washington by telegraph grew to a network of over 600 people across the United States, Latin America, and the Caribbean.

Despite the recent progress and growing interest in citizen science and democratized instrumentation, there are ongoing challenges to scalability, reproducibility, and sustainability of efforts. Options for funding citizen science and maker projects include leveraging crowdfunding and non-traditional funding mechanisms such as micro-grants with a third party evaluator, as well as the use of prizes, challenges, and competitions. Federal government engagement with prizes, challenges, and competitions, in particular, is still relatively new and evolving for many agencies and departments. As a result, the effectiveness of prize and challenge mechanisms may vary widely based on how established the sponsors and candidates are and what the main motivations for each stakeholder might be.

The struggle of a new citizen scientist and maker in their journey to become more established and experienced is paralleled in the entire community's path towards greater visibility and empowerment. In the *President's Strategy for American Innovation*, the American public is called upon to help tackle 21st Century Grand Challenges, defined as "ambitious but achievable goals that harness science, technology, and innovation to solve important national or global problems and that have the potential to capture the public's imagination." Citizen scientists and makers represent a passionate and creative workforce to tackle these formidable challenges. As illustrated in this paper's case study highlights, significant milestones in scientific measurement and creation are attainable in a span of weeks or months. Increasingly, there are new opportunities for an individual's "informal learning" or outside-of-the-classroom contributions to be shared and amplified, whether through a GitHub page, local MeetUps, open source hardware associations, or a formalized college admissions maker portfolio supplement.

By continuing to curate and champion stories of everyday citizens making an impact for societal good, the current Administration can help populate a landscape of maker role models and mentors. Other activities where the U.S. Government can play a supporting role include:

- CONVENING STAKEHOLDERS
  The U.S. Government can be particularly effective at bringing together disparate stakeholders from the private and public sectors through workshops, Google hangouts, and Twitter chats to facilitate cross-pollination and innovative partnerships. By hosting some of these events in-person at regional makerspaces, universities, libraries, and community centers, participants can identify nearby collaborators, yet still have a connection to a national effort.
- SHARING CHALLENGE STATEMENTS
  The U.S. Government is positioned to work with interagency coalitions and other stakeholders to develop and share compelling challenge statements to inspire action. These challenge statements could be linked to data sets, open source tool kits with modular components or "building blocks" for experimentation, and networks of mentors and subject-matter experts.

- DRIVING INVESTMENT
  The U.S. Government can fund or help drive funding for key infrastructure and projects. As noted during the first National Week of Making, commitments from the public and private sectors can come to fruition through awards, challenges, and grants of all sizes. Programs such as DARPA's Robotics Fast Track effort aim to streamline contracting while adhering to Federal Acquisition Regulations. With case studies in innovative contracting and "playbooks" to capture leading practices gaining momentum, all government agencies have the potential to open their doors to non-traditional solvers and harness emerging talent in new ways.

- FACILITATING COLLABORATIVE EXPERIMENTS AND STANDARD METRICS
  The U.S. Government can facilitate collaborative experiments and standard metrics or guidelines that can be used to evaluate solutions. Shared testbeds and frameworks can help encourage transparency and open data in publicly accessible scientific literature and media coverage. Strategic leveraging of government-sponsored university centers, Federally Funded Research and Development Centers can help keep the associated costs of using the testbeds to a minimum.

- CHAMPIONING DIVERSE ROLE MODELS
  By using platforms like the Champions of Change awards to highlight exemplary innovators that reflect a diverse spectrum of ages, genders, and backgrounds, the U.S. Government can help foster an environment where all community members can envision themselves as a maker with meaningful contributions.

- BUILDING AWARENESS AND RECOGNIZING IMPACT
  Providing recognition or encouraging other stakeholders to recognize citizen science and maker projects for their mission impact can help amplify visibility and facilitate scale-up and deployment of projects. Showing citizen scientists and makers that their contribution matters, through Demo Days, blogposts, or formal awards, helps spur additional interest and contributions.

- ENCOURAGING A MAKER CULTURE
  Although the U.S. Government has made significant forays to highlight maker innovations and innovators recently, the typical government environment is strikingly different from a Maker Faire or makerspace. Efforts to spread awareness of how rapid prototyping and creative tinkering can assist in mission objectives can help departments and agencies that do not have maker champions to understand how the maker culture is relevant to them.

More broadly, innovators in government continue to report that it is inherently difficult for bureaucratic organizations to embrace learning by doing and to implement an agile, build-it-as-we-go ethos. Hence, all too often, the "fail fast, learn fast" design and prototyping culture that is so prevalent in the maker community only happens in pockets of the government during employees' free time. Low-resolution prototypes routinely used at innovation hubs like the Stanford d.school as part of the human-centered design process to elicit honest feedback may be met with raised eyebrows and a "this isn't ready for my feedback" response if shown to government leadership expecting polished work.

Senior Advisor for Policy Innovation Josh Marcuse notes, "In my policy role at the U.S. Department of Defense, I routinely observe the 'zero-defect culture' and its negative impact on creativity, efficiency, and speed. It's difficult to propose new or innovative ideas in that culture, and staff have few incentives to try. Many leaders are hungry for less conventional proposals, but unless prototyping or iteration is permitted and early flaws are tolerated, overworked staff rarely can find opportunities to inject creativity or debate into policymaking. When we have used ‘prototyping’ techniques to get leaders’ feedback on concepts earlier in the process, we have accelerated review dramatically. I have also observed that a greater percentage of creative solutions has penetrated a dense thicket of management and process this way, leading to more innovative—and higher quality—policy outcomes.”

To help support a network of innovation advocates and creative problem-solvers throughout government, groups like the Ideation of Community of Practice (ICOP) meet regularly to strengthen their design skills, hear lessons learned from colleagues, and brainstorm how to design participatory experiences that leverage a broad spectrum of ideas and actions. ICOP is currently developing a Government Maker Initiative Playbook, curating examples of how Federal departments and agencies might support, collaborate, and build upon the efforts of the Maker Movement to help advance common goals in areas such as education, economic growth, and broadened STEM education.

One of the themes quickly emerging from Government Maker Initiative Playbook case studies is the need to reduce the barriers between traditionally siloed organizations to help build more effective avenues for collaboration and communication. For example, although NSF has a notably different mission and scope than USAID, efforts in the Maker Movement on monitoring disease outbreaks naturally cut across divisions, offering opportunities for co-designed programs and shared resources. Relatively simple “steady state” mechanisms such as regular newsletters or weekly conference calls can help keep momentum in between more involved “forcing function” events such as interagency-wide Demo Days or the National Maker Faire.

Moreover, real-time, mobile-friendly, easy-to-use online collaboration tools that have been adopted by industry, academia, nonprofits, and the general public are not entering government offices at comparable speeds. With over 4 million people in the Federal workforce, advances in online collaboration could lead to an extensive increase in efficiency and noteworthy employee engagement.

Furthermore, as government departments and agencies begin to scale maker-related efforts more broadly, collaborations with state and local museums, libraries, schools, and community centers can offer an institutionalized public home for further dissemination of insights as well as open source hardware, software, design tools, and other resources. As efforts at the confluence of citizen science and the Maker Movement continue to grow, the lessons learned, success stories, and common metrics curated and maintained through such dissemination platforms can help communities take the next steps in their growth, while strengthening the fabric that unites makers across the Nation.

CONCLUSIONS AND BROADER IMPACTS

The growing momentum at the intersection of citizen science and the Maker Movement offers a unique and compelling opportunity for leaders to foster not only valuable *innovations*, but also a diverse coalition of engaged *innovators* who are ready to tackle society’s pressing challenges.

From environmental monitoring to astronomy experiments, biomedical imaging to disaster response, the sampling of case study highlights described here show a wide spectrum of applications, stakeholder relationships, and models of engagement that can help advance the citizen science and maker ecosystem. As with any new and rapidly evolving grassroots effort, effective leveraging of potential shared resources, available knowledge, and the development of robust networks to link individual contributors is a challenge. By convening stakeholders for pressing, “real world” challenges, facilitating collaborations, and championing informal learning, the U.S. Government can creatively pave the way for sustained science and technology innovation and meaningful engagement.

While the contributions of citizen scientists and makers represent a compelling opportunity just from the sheer number of individuals who can participate, the magnitude of the citizen science and maker network is not the only reason to celebrate and support advances in this realm. The engagement of everyday American citizens ensures a diversity of perspectives—in the problems that are tackled, the scientific questions that are addressed, and the faces of the participants joining the effort. Furthermore, citizen science is a natural platform for democratizing both the instrumentation and the shared knowledge products of scientific discovery, allowing groups and individuals who may be underrepresented in science and engineering the opportunity to discover and help solve relevant and compelling challenges.

Although science and technology can be found all around us in impressive form factors, nostalgic makers often point to their first introduction to tinkering with relatively simple systems. “People used to be able to take apart household gadgets, see the discrete components, and put things back together to learn how things worked. Ironically, technology advances have made it harder to learn from this method—with more ‘black boxes’ of computer chips and integrated devices that keep the magic under wraps,” notes Dr. Dorothy Jones-Davis from the National Maker Faire production team. Indeed, with the growing prevalence of technology that can be embedded in daily life—from automobile touchscreens, to greeting cards that sing, to the numerous sensors in a smartphone—the next generation of scientists is likely to have a staggering spectrum of innovations to build upon. Yet, the citizen science and maker ethos that is growing momentum throughout the country, stretching from small town garages to student summer camps, does not require the shiniest bells and whistles to make a meaningful impact.

At its core, the renaissance of hands-on making and the estimated $29 billion USD injected into the world economy each year by makers reflect a growing reservoir of curiosity, adventurous optimism, and resourcefulness. The development of free beginner and open source resources designed for hands-on education and exploration empowers novices of all ages and all backgrounds to take action, increasing our society’s opportunities for supporting and engaging in informal learning.

With a continued democratization of resources and an influx of self-identified makers across the country, every individual can contribute to a more diverse, vibrant culture of making and citizen engagement—to help our families, our neighbors, and our communities experience the wonder of science and technology.

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