case study series

vol 3

New Visions in Citizen Science

by Anne Bowser
and Lea Shanley

Wilson Center | COMMONS LAB

New Visions in Citizen Science

by Anne Bowser
and Lea Shanley,
Woodrow Wilson Center

November 2013

NEW VISIONS IN CITIZEN SCIENCE

Commons Lab
Science and Technology Innovation Program
Woodrow Wilson International Center for Scholars
One Woodrow Wilson Plaza
1300 Pennsylvania Avenue, N.W.
Washington, DC 20004-3027

www.CommonsLab.wilsoncenter.org

Study Director: Lea Shanley
Editor: Aaron Lovell
Cover design: Kathy Butterfield and Diana Micheli

Available for download free of charge at http://www.scribd.com/collections/3840667/Commons-Lab-Science-and-Technology-Innovation-Program-STIP

The Science and Technology Innovation Program (STIP) analyzes the evolving implications of such emerging technologies as synthetic biology, nanotechnology, and geo-engineering. STIP's research goes beyond laboratory science to explore new information and communication technologies, sensor networks, prediction markets, and serious games. The program provides critical yet nonpartisan research for the policymaking community and guides officials in the design of new governance frameworks. It gauges crucial public support for science and weighs the overall risks and benefits of technology for society at large.

COMMONS LAB

The Commons Lab advances research and non-partisan policy analysis on emerging technologies that facilitate collaborative, science based and citizen-driven decision-making. New tools like social media and crowdsourcing methods are empowering average people to monitor their environment, collectively generate actionable scientific data, and support disaster response.

http://CommonsLab.WilsonCenter.org

Commons Lab Staff

Lea Shanley, Director, Commons Lab
Anne Bowser, Research Assistant
Joe Filvarof, Program Assistant
Aaron Lovell, Writer/Editor

Blog: http://CommonsLab.WilsonCenter.org
Facebook: http://www.facebook.com/CommonsLab
Twitter: http://twitter.com/STIPCommonsLab
Scribd: http://bit.ly/CommonsLabReports
YouTube: http://biy.ly/CommonsLabVideos

The Commons Lab of the Science and Technology Innovation Program is supported by the Alfred P. Sloan Foundation.

About the Authors

Anne E. Bowser is a Graduate Research Assistant at the Commons Lab in the Science and Technology Innovation Program of the Woodrow Wilson International Center for Scholars, where she works to support the needs of federal agencies engaging in open innovation and science. Anne is also a PhD candidate at the University of Maryland's College of Library and Information Science, and a designer of Floracaching, a gamified mobile application for citizen science. Her dissertation research focuses on designing technologies to support public participation in scientific research, with a focus on supporting the needs of traditional citizen scientists while also using gamification (the use of elements of game design in non-game contexts) to motivate contributions from new groups of volunteers. She is also the author a recent primer, Data Policies for Public Participation in Scientific Research.

Lea A. Shanley directs the Commons Lab within the Science and Technology Innovation Program of the Woodrow Wilson International Center for Scholars. Prior to this, Lea was a postdoctoral fellow on the Mapping Science Committee of the National Academy of Sciences, where she co-directed two reports: Precise Geodetic Infrastructure: National Requirements for a Shared Resource; and New Research Directions for the National Geospatial-Intelligence Agency. These reports recommended strategic science and technology priorities for geodesy, hazards monitoring, and national security.

In 2009, Lea was an American Association for the Advancement of Science/ Agronomy Society of America-Crop Science Society of America-Soil Science Society of America Congressional Science Fellow and primary science adviser to the Chair of the Senate Subcommittee on Science and Space. She managed priorities for federal research and development, and she crafted and negotiated legislation addressing earth observation, oceans issues, and hazards research and mitigation. Previously, she had conducted community-based participatory action research in geographic information science at the University of Wisconsin–Madison. This research engaged local and tribal communities in the development and use of decision support systems based on geographic information science, enabling collaborative decision-making for improved emergency management, resource management, and land use planning.

Acknowledgements

This report benefits from the efforts and expertise of many individuals who design, coordinate, or otherwise support various projects in open innovation, including citizen science and crowdsourcing. We would like to thank the following people who offered their time and expertise first during initial interviews, and also during the process of writing, revision, and review:

- Chris Bowser, Hudson River Eel Project
- Zachary Bastian and Michael Byrne, The National Broadband Map
- Theresa Crimmins and Jake Weltzin, Nature's Notebook
- Nolan Doesken, The Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS)
- Paul Earle and David Wald, Did You Feel It? (DYFI?) and Twitter Earthquake Detection (TED)
- Rebecca French and Alice Mayio, EPA's Volunteer Monitoring
- Dan Getman, The Open PV Project
- Stephanie Grosser, USAID's Crowdsourcing to Geocode Development Credit Authority Data
- Allison Llewellyn, NASA's International Space Apps Challenge
- Stewart Michels, The Delaware Bay Horseshoe Crab Spawning Survey
- Tony Murphy, The GLOBE Program
- Lina Nilsson, Tekla Labs
- Arfon Smith, Zooniverse
- Meredith Stewart, Citizen Archivist
- Brian Sullivan, eBird
- Adrien Treuille, Foldit/ Eterna
- Sang-Ho Yun, The ARIA Project

These individuals were not asked to endorse the conclusions that this report suggests, or the method of curating individual projects; nor were they provided a final draft of the report prior to its release. This report exclusively represents the views of the authors, who retain responsibility for the content, including all errors of fact and interpretation.

We would also like to thank TyAnn Lee for her help coordinating interviews with project leads, Caren Cooper and Jennifer Shirk for reviewing portions of the document and providing feedback, Aaron Lovell for editing this report, and Kathy Butterfield and Cherie Worth.

This publication was made possible by a grant from the Alfred P. Sloan Foundation to the Commons Lab of the Science and Technology Innovation Program at the Wilson Center.

Contents

Foreword

Who doesn't want to better tap the potential for open innovation and mass collaboration? At the Commons Lab, we seek to understand how emerging technologies, like social media, mobile devices, and distributed sensor networks, can help us do just that. Toward this end, we work with public and private partners to identify and develop innovative approaches for data collection, analysis, and problem-solving.

Mass collaboration approaches, such as citizen science and crowdsourcing, can produce accurate data for a wide range of uses, quickly and cost-effectively. These approaches enable the public to contribute to scientific research and encourages civic participation in government at all levels. This report describes how "the crowd" has been mobilized to accomplish fascinating and important work—such as collecting air quality and other important environmental data, providing time-critical information for emergency response and hazards research, and solving the structure of an AIDS-related enzyme through a protein-folding game.

But questions remain about the quality and utility of these big data streams. And the greatest barriers to future success in mass collaboration are not only technical, but also social, legal, and institutional. How is crowd-generated data integrated with official data? What are the potential implications of using fused data sets for public sector decision-making and regulation? What will be the impact on policy and for international agreements? To effectively engage the public through open innovation, government must also overcome legal and policy challenges related to privacy, intellectual property rights, Paperwork Reduction Act restrictions, procurement regulations, cybersecurity, and liability.

Our challenge is to find solutions that overcome these barriers. Our goal is to make mass collaboration more trustworthy, efficient, and "actionable" for decision-making. We must develop creative ways to address current challenges and improve processes that support and enable innovation. And we need to evaluate and recommend approaches that will increase the impact of collective problem solving on public sector policies and practices. We also need to foster and sustain a federal community of practice that shares expertise, lessons learned, and best practices. And we need to connect that community with other stakeholders to reduce search costs for the federal government and others seeking collaborators, research results, or other resources.

These activities will strengthen existing projects and help build new partnerships between government and the public it serves.

Lea Shanley

Director, Commons Lab
Science and Technology Innovation Program
Woodrow Wilson International Center for Scholars

November 20, 2013

Executive Summary

Citizen science is one form of open innovation, a paradigm where organizations solicit the efforts of external contributors with unique perspectives who generate new knowledge and technology, or otherwise bolster organizational resources.[1] Recent executive branch policies encourage and support open innovation in the federal government. The President's 2009 Memorandum on Transparency and Open Government[2] charged agencies with taking specific action to support transparency, public participation, and collaboration. Similarly, the Obama Administration's 2013 Memorandum on Open Data Policy—Managing Information as an Asset[3] instructs agencies to support these principles by sharing government data sets. The Preview Report for the Second Open Government National Action Plan, released October 31, 2013, specifically states that the United States will commit to "harness the ingenuity of the public by enabling, accelerating, and scaling the use of open innovation methods such as incentive prizes, crowdsourcing, and citizen science within the Federal Government."[4]

This report showcases seventeen case studies that offer a mosaic view of federally-sponsored citizen science and open innovation projects, from in-the-field data collection to online games for collective problem-solving. Its goal is not to provide line-by-line instructions for agencies attempting to create or expand projects of their own; each agency has a unique mission with distinct challenges that inform project designs. Rather, it offers a sampling of different models that support public contribution, potential challenges, and positive impacts that projects can have on scientific literacy, research, management, and public policy.

Some case studies represent traditional but well-executed projects that illustrate how citizen science functions at its best, by contributing to robust scientific research. Other projects, such as the National Aeronautics and Space Administration (NASA)'s International Space Apps Challenge, evolve from these traditional models, demonstrating how open innovation can address agency-specific challenges in new and compelling ways. Through this progression, the evolution of citizen science begins to take shape, and the full possibilities of open innovation begin to emerge.

Introduction

Every holiday season, teams of volunteers contribute to the Audubon Christmas Bird Count by surveying local bird populations. Audubon initiated this tradition in 1900 as an alternative to the "side hunt," a festive competition where teams competed to hunt larger amounts of game.[5] By asking outdoor revelers to continue their tradition of counting—but to focus on live birds instead of dead ones—Audubon reframed a popular activity to prioritize conservation over sport.

Additionally, the species counts submitted by these volunteers accumulated over time, providing over one hundred years of valuable data. These data support over two hundred scientific publications in fields like population dynamics, species distribution, and community ecology.[6] The Audubon Christmas Bird Count is also important because of how Audubon gathers these data: citizen science, a form of collaboration where members of the public participate in scientific research to meet real world goals. Some volunteers who contribute to citizen science projects like the Audubon Christmas Bird Count collect field data, but others may analyze data sets or solve problems depending on a project's unique needs.

Projects in citizen science and open innovation are usually designed to advance science or create new technologies (see Glossary for working definitions of key terms). But many projects have added impacts including supporting practices in education, management, and public policy. As illustrated by the Audubon Christmas Bird Count, citizen science projects that contribute to scientific research also can support conservation through raising awareness of environmental concerns. Information produced by citizen scientists also may inform policy decisions. The Delaware Bay Horseshoe Crab Spawning Survey[7] provides data to the Atlantic States Marine Fisheries Commission, a regulatory body composed of elected officials from fifteen states, to inform policy decisions about species management. Finally, a number of citizen science projects support formal and informal education. For example, the GLOBE program[8] generates valuable data while using citizen science as a method to teach topics in Science, Technology, Engineering, and Mathematics (STEM) to students around the world.

Many traditional citizen science projects are designed similarly to the Audubon Christmas Bird Count, where volunteers contribute regular observations of their natural environments. But this model no longer represents the status quo.

First, while some projects are annual or ongoing, others—like Bioblitzes, or hackathons—are designed as one-time events. Second, many projects now support digital participation, engaging a global audience in a wide range of scientific activities through online platforms, social networks, and digital games.

By asking for help classifying images of galaxies or transcribing ship logs from historic arctic voyages, projects in the Zooniverse suite[9] lets volunteers contribute to science from their personal computers, and in the comfort of their own homes. Foldit, a citizen science project that has contributed to the study of HIV/AIDS, is designed as a collaborative protein folding game.[10]

Citizen science boasts a range of projects with incredible impacts, but not all successes are easy wins. For example, most projects must justify their initial decision to use volunteers. Skeptics in the scientific community argue that volunteers cannot produce research-grade data, while skeptics in federal agencies argue that policies such as the Privacy Act[11] or the Paperwork Reduction Act[12] create administrative barriers. While both challenges are valid, both have been overcome. Zooniverse used empirical analysis to demonstrate that the galaxy classifications produced by volunteers are as accurate as those produced by professional scientists.[13] The Federal Communication Commission (FCC)'s and US Agency for International Development (USAID)'s successful navigation of federal policies and regulations are documented as examples of what is possible in the federal open innovation.[14]

The projects included in this report span topics as diverse as development, education, energy, the environment, public health, telecommunications, natural resources such as air and water, and disaster response. These case studies are highlighted so that others can witness the different implementations of open innovation and also the hurdles that projects encounter. As a whole, these case studies showcase the range of possibilities that citizen science and open innovation can achieve.

1

Volunteer Monitoring at the EPA

Citizen science to support agency missions

Background

The Environmental Protection Agency (EPA) was created to protect human health and the environment. To fulfill this mission, the EPA develops and enforces regulations, gives grants to states and other institutions, investigates environmental issues, and educates the public.[15] The EPA coordinates its efforts through ten regional offices, and delegates responsibilities to states and Native American tribes. The EPA supports volunteer air and water quality monitoring directly through the provision of resources, and also indirectly through the support of state and regional offices.

Improvement through innovation

The volunteer water monitoring program at the EPA exemplifies how the agency supports volunteer citizen science activities. EPA provides volunteers with a listserv, a national directory of water monitoring programs, and conference support.[16] Volunteer monitoring is also supported through regional offices state environmental agencies; for example, regional offices may act as contacts for local organizations and provide technical assistance on quality control and access to equipment.[17] Many local programs also receive funding through EPA Section 319 grants for implementation of pollution management programs, which are coordinated at the state level.[18] Volunteer monitoring may also help members of the public better understand and address environmental or public health issues in their local communities.[19]

Evidence of impact

Volunteers who participate in EPA's water monitoring program receive training in pollution prevention, learn how to test water quality, and help detect and restore problem sites.[20] These activities empower volunteers to address pollution problems while also contributing data used by decision-makers in local, state, and federal governments. In some cases, volunteer activities can lead to regulatory action. Citizen scientists monitoring air quality in upstate New York detected high levels of benzene, a known carcinogen, in their community. These volunteers then contacted the New York State Department of Environmental Conservation (DEC) for support. A year-long investigation by the DEC used air monitors at four locations to measure fifty-six air toxins, ultimately confirming benzene levels that exceeded the DEC's health-based annual guidelines.[21] This data spurred enforcement actions by the DEC and EPA. Furthermore, in March 2013, the manufacturer and an executive were convicted of criminal charges for pollution.

Figure 1. Volunteers monitor the health of local streams.

Name:	Volunteer Monitoring at EPA
Description:	The EPA supports volunteer air and water monitoring projects coordinated at the state and local levels
Since:	1998
Fields:	Water/ Air
Sponsor:	EPA
Website:	http://water.epa.gov/type/rsl/monitoring/

Barriers to success

Data quality is an often-cited issue in citizen science, and data used for regulatory purposes must meet especially rigorous standards. To support volunteer monitor program and improve data quality, EPA provides volunteers with a general guide to quality assurance project plans[22] and also publishes specific methods for monitoring estuaries, lakes, streams, and wetlands.[23] While EPA does not use volunteer data directly, many states accept data collected by volunteers in assessments submitted under sections 304(b) and 303(d) of the Clean Water Act.[24] Some states, such as Iowa, also report volunteer monitoring data to EPA through the STORET database.[25]

2

The Delaware Bay HSC Spawning Survey

Monitoring to support conservation policy

Background

Limulus polyphemus, a species of horseshoe crab native to the Delaware Bay, is vital to its local ecosystem and to the health of human beings. Eleven species of migratory shorebirds, including the threatened Red Knot, rely on horseshoe crab eggs to fuel migrations to their Antarctic breeding grounds.[26] And Limulus Amebocyte Lysate (LAL), a compound found in the blood of horseshoe crabs, is the key ingredient in a standardized test used to check pharmaceuticals for bacterial contamination.[27] Horseshoe crabs are also used as bait in eel and conch fisheries. Due to increased demand from various industries, a number of states reported increased harvests between 1990 and 1996.[28] At the same time, birders and ecologists noted a population decline. After management at the state level proved ineffective, state officials and citizen lobbyists appealed to the Atlantic States Marine Fisheries Commission (ASMFC), a regulatory body of elected and appointed officials from fifteen states bordering the Atlantic, to accept the Horseshoe Crab as a managed species.[29]

Improvement through innovation

The ASMFC implemented a species management plan in 1999, requiring each state to conserve key habitats and enforce caps for commercial fishing.[30] Because both approaches require a baseline understanding of horseshoe crab populations, state, federal, and university researchers developed a survey to index the population during spawning season. To ensure validity of the result across Delaware and New Jersey beaches and through seasons, survey dates are coordinated to the exact minute of high tide.[31] This approach requires efforts greater than professional scientists alone can provide.[32] The Delaware Bay Horseshoe Crab Spawning (HSC) Spawning Survey was developed as a bay-wide effort to recruit, train, and deploy citizen scientists willing to help survey horseshoe crabs. The National Estuarine Research Reserve System (NERR) began coordinating the project in 2011.

Evidence of impact

Each year, hundreds of volunteers collect data at thirteen beaches in Delaware and twelve in New Jersey on each of twelve distinct dates (figure 2).[33] This data is used annually by the ASMFC to inform policy decisions about species management. For example, Addendum IV was passed by the ASMFC in 2006 to reduce commercial fishing quotas by thirty-three percent in response to concerns about Red Knot population decline.[34] Scientists also use volunteer data to study topics such as the relationship between spawning activity and environmental factors such as wave height or water temperature. [35]

Figure 2. Each year, Delaware volunteers survey horseshoe crabs on 12 nights in May and June.

Name:	The Delaware Bay HSC Spawning Survey
Description:	Volunteers and scientists survey horseshoe crab spawning on twelve dates in late spring
Since:	1999; NERR coordination began in 2011
Fields:	Water / Biodiversity
Sponsors:	The National Oceanic and Atmospheric Administration (NOAA')s National Estuarine Research Reserve System; U.S. Fish and Wildlife Services; USGS; State agencies
Website:	http://horseshoecrabsurvey.com

Barriers to success

Limuli Labs, a commercial extractor of LAL, began using volunteers to monitor horseshoe crab populations in the early 1990s.[36] Their practices were pilot efforts and improved over time. Unfortunately, while the results of their research suggested a collapse in the population, the continual improvements to their sampling methods confounded the results.[37] After the ASMFC began managing the horseshoe crab, the ASMFC collaborated with Limuli Labs and the University of Delaware to design statically robust methodologies based on the initial work. Thus, the rigor of current practices benefited from knowledge of Limuli Lab's early methods, and the cautionary tale of their rejected research.

3

The Hudson River Eel Project

Citizen science juvenile American eel surveys

Background

Bioindicators are biological processes, species, or communities that are highly sensitive to changes in their environments.[38] One North American bioinidicator is *Anguilla rostrata*, the American Eel (figure 3). Each spring, juvenile eels embark on an 8-week migration from breeding grounds in the North Atlantic Ocean to freshwater systems in North America, including the Hudson River watershed. The predictability of this migration means that scientists or volunteers who monitor eels generate valuable data that informs species management, and also can reveal subtle changes in environmental processes as data accumulates over time.

Improvement through innovation

For an eight-week period each year, volunteers for the Hudson River Eel Project gather daily data from streams at ten to twelve sites in Upstate New York. Participants use sampling standards maintained by the Atlantic States Marine Fisheries Commission, where eels are captured in specially designed fyke nets, weighed, and then released upstream.[39] These nets are strategically placed next to the first natural barrier (waterfalls or small damns) at the mouth of a tributary. This standard protocol allows comparison between sites, but also lets volunteers help the eels safely navigate these hurdles.

Evidence of impact

Between 2008 and 2014, volunteers and scientists captured, measured, and released 214,974 juvenile eels. Annual survey data is reported to both state and coast-wide management councils through NERR and NOAA. Because eels are bioindicators, these surveys provide important benchmarks for future conservation projects.[40] The Hudson River Eel project also benefits volunteers, who learn about monitoring practices and engage with their local communities. To this end, project managers deliberately reach out to schools in low-income communities throughout the Hudson Valley, from New York City to Albany.[41]

Barriers to success

Citizen science projects that ask volunteers to observe charismatic species, such as butterflies or birds, enjoy access to large groups of passionate hobbyists. Eels have a less obvious appeal, making the recruitment and retention of volunteers to monitor eels is a significant issue. Project managers initially solicited help from high school science teachers working at schools close to ideal sampling sites, convincing two to three early adopters to

Figure 3. Juvenile "glass" eels.

Name:	Hudson River Eel Project
Description:	Professional and citizen scientists survey eel populations for eight weeks each spring
Since:	2008
Fields:	Water / Biodiversity
Sponsors:	NOAA's National Estuarine Research Reserve System
Website:	http://www.dec.ny.gov/lands/49580.html

help engage high school volunteers. These teachers shared their experiences with colleagues in other districts, and also returned with new students the following year. In this way, the tactic of collaborating with formal educators ensured a steady stream of data while also supporting scientific education and community engagement.

While the Hudson River Eel Project employs "common sense field practices" to ensure the safety of their volunteers, liability is a growing concern.[42] Commercial monitoring sites that allow the project to use their property are especially concerned that volunteers are often under 18. To address these concerns, the Hudson River Eel Project works with schools to get insurance riders for volunteers who monitor local streams. The project also works with New York State to secure letters of indemnity that protect specific sites from complaints.[43]

4

Community Collaborative Rain, Hail, and Snow Network

A national network of volunteer weather monitors

Background

On July 28, 1997, a record-breaking storm descended on Fort Collins, Colorado, dumping fourteen inches of water on the city in thirty hours.[44] The resulting flooding caused five fatalities and $200 million in damages. But not all parts of the city were equally affected; some areas received the full fourteen inches of rain, while others recorded as little as two inches of precipitation. This discrepancy was so severe that it may have prevented emergency responders from recognizing the full magnitude of the storm. The Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS) was founded in 1998 to improve the mapping and reporting of severe storms.

Improvement through innovation

CoCoRaHs supported activity in Colorado until 2003, when the project received a National Science Foundation grant to expand into Wyoming, Nebraska, and Kansas.[45] This allowed CoCoRaHS to hire key staff, such as a web developer who implemented the technology to support multi-state participation. As knowledge of CoCoRaHS spread, scientists began requesting support for data collection across the United States. Scaling up was dependent on recently implemented technologies, but also the time of additional staff. CoCoRaHS responded by offering new states access to their technological platform, but requiring each state to establish their own network of volunteer leaders responsible for recruiting, training, and retaining local monitors. Motivated local leaders have helped grow CoCoRaHS to more than 10,000 active volunteers in all 50 states and several Canadian provinces.

Evidence of impact

The data collected by CoCoRaHS volunteers is combined with information from satellites and radar to create daily precipitation maps published by the National Weather Service (NWS; figure 4). River forecast centers use this mapped data to understand municipal water supplies and hydropower production, or for flood prediction.[46] Understanding potentially extreme levels of precipitation is also key to designing infrastructure such as bridges, spillways, and damns. For example, the US Army Corps of Engineers elected to use CoCoRaHS data from recent Colorado floods to inform future engineering.[47] Finally, CoCoRaHS data is used by farmers and the USDA to understand crop conditions and predict irrigation costs or market cycles.[48]

Figure 4. A standardized rain gauge used by CoCoRaHS volunteers.

Name:	The Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS)
Description:	Volunteer weather monitors check standardized rain gauges to measure precipitation
Since:	1998
Fields:	Weather
Sponsors:	NOAA; NWS; National Science Foundation (NSF); Colorado State University; National Hydrologic Warning Council; State agencies
Website:	http://www.cocorahs.org

Barriers to success

Ensuring that volunteers collect research-grade data is a common problem in citizen science. CoCoRaHS volunteers measure precipitation with standardized rain gauges, which are low-cost ($30) and provide extremely precise data.[49] Unfortunately, CoCoRaHS is unable to provide complimentary rain gauges to everyone who expresses interest in the project. The need for precision, therefore, has the unfortunate effect of discouraging initial participation for some potential volunteers. CoCoRaHS does work hard to retain existing volunteers. Because many citizen scientists are motivated by personal contact with scientists or project managers, CoCoRaHS encourages regional coordinators to reach out to volunteers on an individual basis.[50] Additionally, CoCoRaHS staff regularly keeps in touch with participants via social media, web posts, and direct e-mail. Interesting facts about weather and climate are posted daily in the "message of the day," which is shared with volunteers after they submit data, providing additional motivation for participation.

5

The GLOBE Program

Learning and education to benefit the environment

Background

Global Learning and Research to Benefit the Environment (GLOBE) is a worldwide community of students, teachers, scientists, and citizens working together to better understand, sustain, and improve earth's environment at local, regional, and global scales. GLOBE students conduct local scientific research investigations on five core areas of Earth system science: atmosphere, phenology, hydrology, land cover/biology, and soil. Each investigation area consists of scientific measurement protocols and learning activities.[51] Increasing STEM literacy is a primary goal of GLOBE, and all GLOBE teachers go through a training and certification process. The protocols that they learn, developed by scientists and educators, enable students to contribute standardized, research-quality data. In this way, GLOBE is the first organization to marry experiential learning with scientifically valuable citizen science activities.

Improvement through innovation

GLOBE is implemented through a network of partners including educational institutions, non-profit organizations, and government centers in the U.S. and member countries.[52] The GLOBE partners are responsible for the recruitment and training of teachers. Each partner is empowered to implement the program to meet its needs in a local context. This allows partners to design teacher training in accordance with state or national educational standards or their own best practices, to develop relationships with local scientists conducting Earth science research, and to collaborate with other GLOBE partners focusing on similar areas of inquiry around the world. The infrastructure coordinating and supporting this worldwide community using the Internet and information systems is provided and managed by NASA.

Evidence of impact

Since 1995, 112 countries have participated in The GLOBE Program (figure 5).[53] These participants include 58,000 teachers and 1.5 million students who have contributed more than 100 million measurements. As of 2013, 108 countries are participating in the program.[54] GLOBE is valued by scientists, teachers, and students in multiple ways. For example, Mexican scientists used data collected by students in the Guadalajara region to identify a correlation between aerosols and respiratory disease.[55] Students who are involved in GLOBE as part of a science program have scored higher on state science scores.[56] Students also practice stewardship over environmental resources; in one case, zstudents in California successfully lobbied their city council to preserve a wooded area for educational purposes rather than selling it to real estate developers.

Figure 5. GLOBE schools across the world.

Name:	Global Learning and Research to Benefit the Environment (GLOBE)
Description:	By combining experiential learning with citizen science, GLOBE increases STEM literacy while collecting valuable data
Since:	1995
Fields:	Education / Science
Sponsors:	NASA; NSF; Supported by NOAA and Department of Security (DOS)
Website:	http://globe.gov

Barriers to success

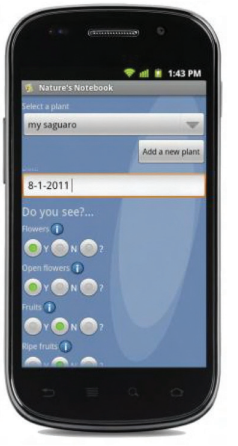
Many open innovation projects that allow children under thirteen to collect data are concerned with COPPA, the Children's Online Privacy Protection Act.[57] In GLOBE, adult teachers are the primary points of contact that receive educational materials and manage online student accounts. The students who use these accounts are able to perform limited activities such as enter and retrieve data, use visualization tools, and communicate with peers. By using teachers as intermediaries and imposing limitations on account activities, GLOBE successfully demonstrates COPPA compliance.[58]

6

Nature's Notebook

Connecting people with nature to benefit our changing planet

Background



Nature's Notebook, a program of the USA National Phenology Network (USA-NPN), engages professional and citizen scientists alike in recording observations of plant and animal phenology, the timing of seasonal biological events like leafing and flowering of plants and migration or hibernation of animals. Phenology affects events such as harvest cycles, the timing of human allergy season, and the outbreak of wildfires.[59] Understanding phenology helps people decide when to irrigate land or manage insect pests, when to conduct prescribed burning in forests, or when to harvest agricultural crops.[60]

Improvement through innovation

The tradition of large-scale phenology monitoring dates to the late 1950s, when volunteers across the country used U.S. mail to submit observations about lilacs and honeysuckles to the United States Department of Agriculture (USDA).[61] The USA National Phenology Network (USA-NPN) was founded in 2007 by the USGS, National Science Foundation and other agencies to help science and to support society by promoting phenology as a tool to understand and adapt to changing environments. As of 2013, more than 2,600 Nature's Notebook volunteers have submitted phenological data about hundreds of species of plants and animals (figure 6).[62] Their data and results are shared with scientists, resource managers, policymakers, and members of the public.

Evidence of impact

Spring is often measured by "budburst," or the first appearance of new leaves on plants.[63] A "false spring" occurs when early warm weather coaxes prematurely plants out of dormancy, leaving young leaves vulnerable to frost. In 2012, Nature's Notebook participants documented a false spring that caused significant agricultural losses across the United States, including half a billion dollars of damages to Michigan fruit trees alone.[64] Within five years, Nature's Notebook data should enable scientists to "forecast" spring weeks in advance and, within ten years, scientists might predict spring months in advance.[65] This would enable government and private organizations to take protective measures against forecasted "false springs," as well as to inform decisions on when to plant crops and how to manage disease.[66] Longer term phenology data could influence policy on agriculture, natural resource management, and carbon sequestration.[67]

Figure 6. Volunteers who contribute to Nature's Notebook can record data using paper-and-pencil forms, or through a mobile device.

Name:	Nature's Notebook
Description:	Professional and citizen scientists collect natural observations about the timing of seasonal events
Since:	2007
Fields:	Ecology / Biology
Sponsors:	USA-NPN through U.S. Geological Survey (USGS), NSF, and others
Website:	https://www.usanpn.org/natures_notebook

Barriers to success

Like many citizen science projects, Nature's Notebook must argue for the scientific validity of volunteer observations. To best support science and decision-making, the USA-NPN seeks repeated observations of the same species through time. To meet this goal, the USA-NPN has implemented multiple models for obtaining volunteer observations through Nature's Notebook.[66] In the first model, individual observers participate independently, collecting and submitting observations from locations such as their yards. This requires both dedication and time. In a second model, observers work together to make repeated observations at an established long-term monitoring site such as a school, nature center, or national park. USA-NPN staff expect that this latter model will yield more consistent observations for a longer period of time. One reason for this may be that these shared sites support training, such as that provided by teachers or park rangers, and may facilitate socialization or community involvement and thus increased engagement.[69]

7

eBird

Birding to support science, conservation, and policy

Background

Birds are sensitive environmental indicators that can reveal ecosystem health and signal environmental change.[70] Birds are also attractive, plentiful, and diurnal creatures observed by an enthusiastic community of hobbyists around the globe. Many of these birders record their sightings in checklists, such as state or country lists, which note the species observed in different geographies, or life lists, which document a lifetime of bird observations.[71] eBird is a real-time, online checklist program designed to maximize the utility of these observations by collecting checklists from a large number of birders and aggregating them into a single database.[72]

Improvement through innovation

After birding excursions, volunteers submit data on species presence or abundence to eBird. Because birders are hobbyists with varying expertise, these observations are fed through an automated quality control filter designed to detect data outliers that require human review.[73] eBird maintains a network of more than 550 regional volunteers who review documentation and decide whether to accept an outlier observation. This rigorous process of quality control ensures that volunteer data is research grade.

Evidence of impact

As of mid-2013, more than 150,000 registered eBird users contributed 140 million observations.[74] eBird provides a number of interactive visualization tools—such as species range maps, and bar charts illustrating seasonal distribution—that help the public understand eBird data (figure 7).[75] eBird also shares raw data with international biodiversity collections, such as the Global Biodiversity Information Facility, and allows individual users to download a raw data set.[76] This raw data is used by individual researchers working on projects in fields as diverse as species distribution modeling, statistics, and computer science.[77] Non-government organizations and government users also download the data to estimate species occurrences on public and private lands.[78] The 2013 State of the Birds Report, published as part of a collaboration between the United States Department of Agriculture (USDA) and the Department of the Interior (DOI), used modeled eBird data to demonstrate how private land conservation incentives are linked to species distribution.[79]

Barriers to success

Engaging and retaining volunteers is a common challenge in citizen science, and eBird initially had limited success on this front.[80] Recognizing the habits of birders who maintain

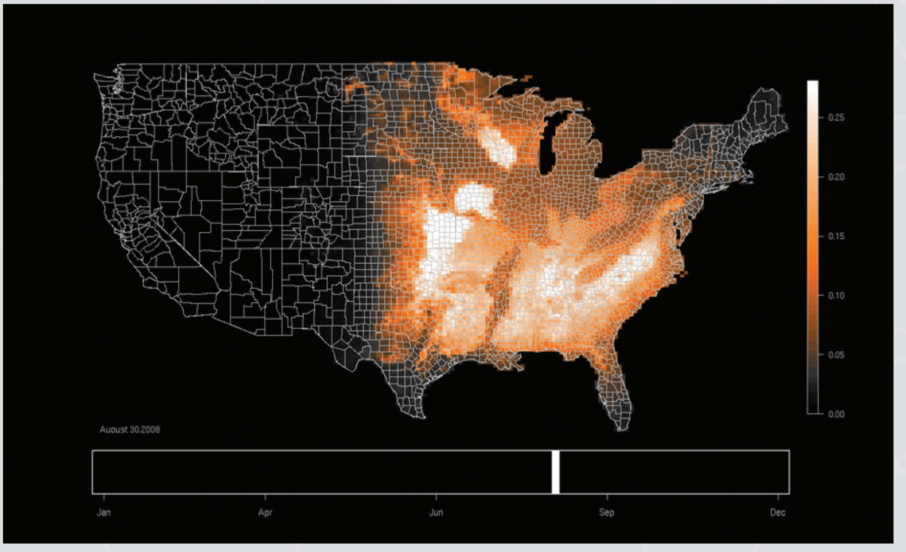


Figure 7. In this visualization, eBird data is used to model the species occurrence of the Eastern Bluebird in August 2008.

Name:	eBird
Description:	Volunteer birders upload their observations to create an open-source set of global species distribution data
Since:	2002
Field:	Ecology / Biology
Manager:	Cornell Lab of Ornithology
Sponsors:	NSF, Wolf Creek Charitable Foundation; Leon Levy Foundation
Website:	http://ebird.org

paper checklists, “My eBird” was designed as a virtual species checklist that aggregates all of a user’s data on a single page. By allowing eBird users to manipulate their own data in addition to community data, My eBird successfully demonstrates eBird’s personal value to each individual birder.[81] Recognizing that many birders are competitive, the Daily “Top 100” list of contributors was created to motivate volunteers to gather (and share) more data than their peers. eBird volunteers are also motivated by the desire to contribute to a global database for science and conservation. However, this motivation is unlikely to spur large-scale participation in the absence of personal rewards for using the eBird platform.[82]

8

Citizen Archivist

Crowdsourcing to transcribe our National Archives

Background

The National Archives Records Administration (NARA) is the nation's record keeper, preserving documents so citizens can discover, use, and learn from historical records.[83] Even though less than three percent of all federal records are considered permanent, the National Archives holds more than 10 billion paper records and millions of still photographs, electronic recordings, and presidential records.[85] NARA works to digitize and host these records online for public access, but searching for an exact record—even online—is a process often compared to looking for a needle in a haystack.[85]

Improvement through innovation

"Citizen archivist" is a term coined by David Ferriero, the 10th Archivist of the United States, to describe how the public can contribute to the records of the National Archives and help make these records more accessible online.[86] The Citizen Archivist Dashboard[87] coordinates NARA's crowdsourcing initiatives, which include tagging archival records, transcribing documents, editing wiki articles, and contributing to *Old Weather*, a gamified transcription project by Zooniverse (figure 8). Some activities use tools developed by the agency, such as the transcription tool Transcribr. Other activities rely on existing platforms such as Wikipedia and Flickr. Hosting the Citizen Archivist Dashboard as a web portal while also utilizing these external platforms allows NARA to reach a broad audience of volunteers with diverse interests and motivations.[88]

Evidence of impact

Citizen Archivists have transcribed millions of hand-written or typed records into machine- readable form. For example, more than 170,000 volunteers contributing to the 1940 Census Community Indexing Project indexed 132 million names in only five months.[89] Citizen Archivist is also an early story of success that legitimized crowd-sourcing in federal agencies. The Administrative Conference of the United States awarded NARA the 2012 Walter Gellhorn Innovation Award for innovation and best practices in government.[90] NARA also shares its tools with other agencies and the general public, releasing Transcribr as open source on Drupal in 2012.[91] As of September 2013, the code has been downloaded 653 times. NARA expects federal agencies and cultural institutions to improve these types of open-source crowd-sourcing tools over time, creating an ecosystem that facilitates quicker improvements and lower costs.

Figure 8. From the citizen archivist dashboard, volunteers can access a variety of citizen science projects coordinated by NARA.

Name:	Citizen Archivist
Description:	Volunteers transcribe images into machine-readable text
Since:	2010
Field:	Digital Humanities
Sponsor:	NARA
Website:	http://www.archives.gov/citizen-archivist

Barriers to success

With more than ten billion pages of records, NARA has to design crowdsourcing activities that do not require significant staff resources for reviewing public contributions.[92] Focusing on transcribing records, a task beyond the scope of potential staff activities, allows NARA to experiment in a low-risk environment. The activities of citizen archivists are not a substitute for the duties of professional archivists; rather, the collaboration with the public allows NARA to conduct activities in support of its mission that would not otherwise be possible.

9

Zooniverse

A platform for digital citizen science

Background

Research in scientific fields like astronomy, particle physics, and bioinformatics generate petabytes of data.[93] This "data deluge" has led some scientists to name data-intensive science, which requires new tools and methods of analysis, as the fourth paradigm of scientific research.[94] The Zooniverse platform harnesses the efforts of volunteers to help scientists cope with vast quantities of data that they would be incapable of analyzing alone.[95]

Improvement through innovation

Zooniverse began in 2007 as Galaxy Zoo, an astronomy project that asked volunteers to classify the shapes of different galaxies photographed in the Sloan Digital Sky Survey.[96] Since then, Zooniverse has expanded to become a collection of digital citizen-science projects curated and built by the Citizen Science Alliance (figure 9). These projects ask different research questions and utilize a range of research methods, and are created as potential collaborators approach Zooniverse with large data sets that could be analyzed or interpreted by citizen science volunteers.[97] Some Zooniverse projects still support astronomy; for example, Moon Zoo volunteers recently classified 2,324,944 images of the moon.[98] Others projects ask volunteers to complete such diverse tasks as transcribing ship logs to study climate change[99] or researching the lives of the Ancient Greeks.[100]

Evidence of impact

Citizen scientists playing Galaxy Zoo contributed more than 40,000,000 individual classifications that led to a catalogue of nearly one million galaxies.[101] This data is useful to scientists who study galactic formation and evolution. In addition to systematically producing large sets of data, Galaxy Zoo volunteers can make serendipitous discoveries that would be missed by an algorithm performing the same task. Hanny's Vorwerp, a galactic anomaly discovered by a Dutch schoolteacher in 2007, challenges scientists' understanding of how galaxies appear, evolve, and die.[102] Other projects in the Zooniverse suite are exposed to an equally large volunteer base and report similar success in their own respective domains.

Barriers to success

For Zooniverse, legitimizing crowdsourcing data analysis was a necessary precursor to producing results accepted by the scientific community. The first academic paper on Galaxy Zoo describes how researchers use data reduction and weighted classification to produce galaxy classifications consistent with those of professional astronomers.[103] Establishing the validity of data produced by citizen scientists supports the use of the catalogue created in

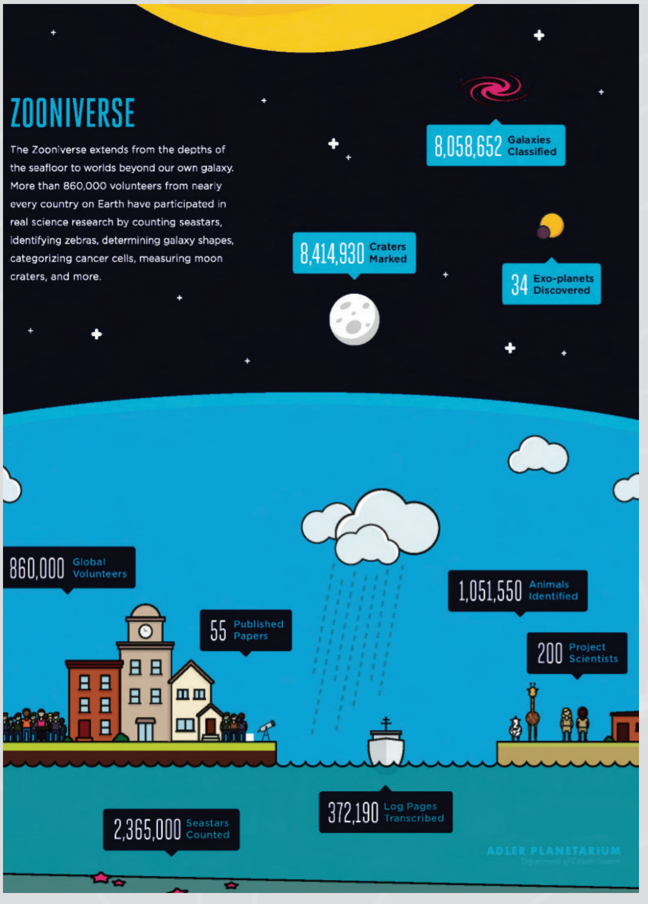


Figure 9. This inforgraphic details the immense "Zooniverse" by showing the data, scientists, and volunteers involved.

Name:	Zooniverse
Description:	An online portal of digital citizen science projects
Since:	2007
Fields:	Science
Sponsors:	Each Zooniverse project maintains its own list of sponsors
Website:	http://www.zooniverse.org

the first version of Galaxy Zoo and justifies the expansion of Zooniverse to include other data sets.[104] While the media often characterizes Zooniverse as a game, the project deliberately emphasizes science over education and engagement, as suggested by the slogan "real science online." Similarly, in an early effort to establish credibility Zooniverse chose to solicit funding from research streams instead of the education and outreach sources popular with other citizen science projects.[105]

10

Tekla Labs

Building tools for science and discovery

Background

Commercial lab equipment can be prohibitively expensive or not adequately tailored to a lab's specific needs and many research labs build their own equipment to supplement purchased tools. These in-house builds span a wide range of approaches and are found in some form in nearly all research labs. For example, a centrifuge can be fashioned from a kitchen blender at a fraction of the cost of purchasing a manufactured device.[106] Many researchers working in laboratories have the know how to build or enhance their instruments, but this information is not widely available to the general public or shared between research groups. Tekla Labs is a library of open-source documents dedicated to filling this niche by providing guides for creating high-quality, do-it-yourself (DIY) lab equipment.[107]

Improvement through innovation

Materials in the Tekla Labs library include guides for constructing science lab equipment; guides for "Lab Hacks," or simple infrastructure solutions to improving research flow in the lab; and guides for approaches such as 3D printing of lab equipment solutions (figure 10).[108] The equipment is built or tested by members of the Tekla Labs community and other researchers and makers globally. As of October 2013, Tekla Labs guides have been accessed approximately 5,000 times.[109] These guides are hosted with Wiki and related software, allowing any registered user to contribute to existing guides or create guides of their own. Because all guides are licensed by a Creative Commons Share-Alike license,[110] users may redistribute guides among their own communities. The Tekla Labs website also supports a forum where members can discuss projects, ask questions, and request new guides.[111]

Evidence of impact

Tekla Labs was created to support laboratories at small universities and colleges that receive less funding than large research institutions, with a vision for both the United States and other countries.[112] Securing funding is especially challenging in the developing world, where the potential for scientific impact is also greatest.[113] At the same time, potential for great impact exists also in the United States, with the ability to affordably build whole class-room sets of equipment. This would enable more high school and college students to experience science hands-on in classes and labs. Furthermore, the act of creating a tool supports a deeper understanding of how that tool works, which further engages populations in the process of scientific research.[114]

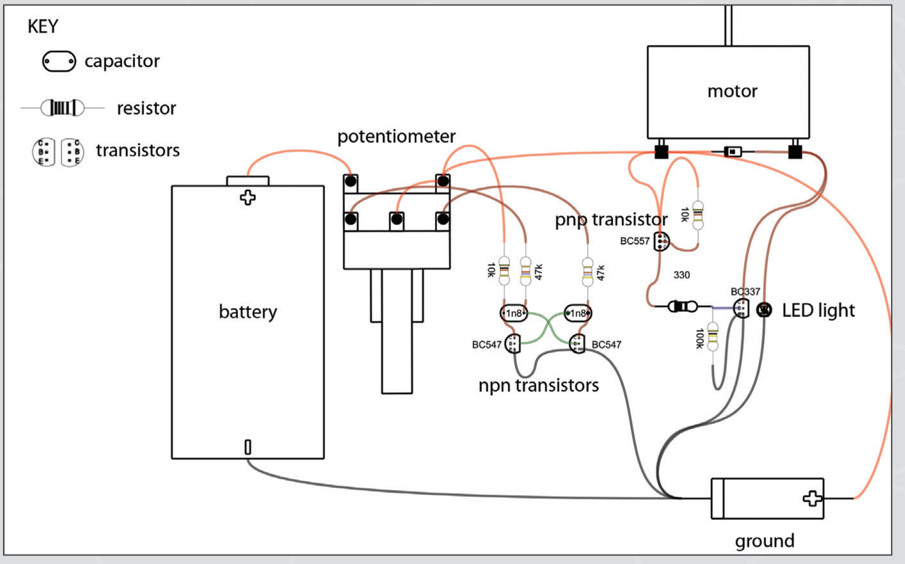


Figure 10. Instructions for constructing a magnetic stirrer from the Tekla Labs "Magnetic Stirrer" guide.

Name:	Tekla Labs
Description:	Open source guides for DIY lab equipment
Since:	2011
Fields:	Science / Technology
Sponsors:	UC-Berkeley
Website:	http://www.teklalabs.org

Barriers to success

Open innovation has demonstrated success in software development with the open source movement, and in knowledge sharing with sources ranging from Wikipedia to the PLoS (Public Library of Science) series of peer-reviewed journals.[115] But openness during the process of scientific research is still significantly less common than the sharing of scientific results. As an early innovator, Tekla Labs encounters new permutations of established problems. For example, poorly constructed instruments could lead to faulty data. Tekla labs tests submitted equipment designs and also supports quality control of their guides with a flagging system that allows community members to mark omissions such as missing images or incorrect prerequisites and or to expose improper directions or unnecessary steps.[116] Soliciting high-quality, detailed contributions is also difficult. To this end, Tekla Labs is co-sponsoring a "Build My Labs" contest, a judged competition that solicits blueprints for DIY lab equipment that offers more than $5,000 in prizes.

11

NASA Space Apps Challenge

Collaborative problem solving with open source solutions

Background

A hackathon is a model of mass collaboration where volunteer software developers create new technologies such as mobile applications, often for a prize or other reward.[117] As the average cost of hosting a hackathon is $5,000 and the average duration is a single weekend,[118] hackathons are ideal for inexpensively generating innovative solutions to open-ended questions.[119] NASA's International Space Apps Challenge is an exemplary federally sponsored hackathon where teams use public data to solve challenges in hardware, software, citizen science, and information visualization.[120]

Improvement through innovation

The NASA Space Apps Challenge is, in fact, a collection of challenges: seventy-five challenges were posed in 2012, and fifty-eight in 2013.[121] Each challenge is written by a government or private partner who possesses a compelling technical problem and the data set to solve it, but lacks the methodology or personnel required to craft a solution. Challenges may be closed or open ended. "Earth From Space" solicits an app to overlay satellite imagery on a global map, while "We Love Data" simply asks participants to "rethink how people interact with space data in new and meaningful ways."[122] While the hackathon is technically a 48-hour event, challenges are advertised in advance to facilitate coordination among and between teams. NASA does not offer a financial reward, though local sponsors offer various incentives: for a 2013 challenge in Philadelphia, the National Aerospace Training and Research Center offered flight suits to the teams in the Philadelphia area with the best solutions.[123]

Evidence of impact

In 2012, 2,083 participants representing 25 cities and 17 countries collaborated to submit 101 solutions. NASA ambitiously planned a 2013 challenge at double this scale; in fact, between 2012 and 2013 the number of cities tripled, the number of participants quadrupled, and the number of submissions increased by seven-fold (figure 11).[124] As the average cost to develop an app at NASA is $150,000 to $200,000, the financial valuation of these solutions far exceeds the actual cost of hosting an event.[125] Impacts also extend outside of NASA and beyond technological gains. NASA encourages other federal agencies to write Space Apps challenges to solve their own problems and experience mass collaboration firsthand.[126] In 2013, DOE, EPA, and USDA all submitted their challenges and data to Space Apps volunteers. The USDA challenge for a backyard poultry farming application to help households enter agriculture inspired a submission that won the People's Choice Award.[127]

Figure 11. Photographs submitted by organizers and Volunteers document the 2013 event in locations such as Athens.

Name:	NASA International Space Apps Challenge
Description:	An annual hackathon where volunteers collaborate to produce technical solutions to important global challenges
Since:	2012
Fields:	Technology / Space
Sponsors:	NASA; Various agencies sponsor specific challenges
Website:	http://spaceappschallenge.org/

Barriers to success

Hackathons hosted by private companies have a clear model of participation: Volunteer developers compete during a set time frame to produce the best possible application, to be owned and marketed by the hackathon host.[128] But federal mass collaboration challenges assumptions about how government works by asking significant questions about funding, ownership of data and applications produced through mass collaboration, and the role that citizens play in their government.[129] These questions are similar to those evoked by the Obama Administration's Open Government initiative. In this case, NASA treated the Space Apps Challenge as a tangible if experimental manifestation of what open government can be. By contextualizing the Space Apps Challenge within a national action plan, project leaders secured internal buy-in and demonstrated a model of how the ideals of open government can be achieved with tangible benefits.

12

Foldit and Eterna

Solving puzzles for science and health

Background

Modern science is characterized by complex challenges that require tremendous amounts of human attention to solve. Players of digital games are practiced and highly motivated problem solvers who spend their free time achieving epic but largely imaginary wins.[130] Scientific discovery games allow individuals without formal training to contribute to scientific research, inspiring gamers to help decipher the causes of disease.[131]

Improvement through innovation

Foldit, a digital multiplayer game where players develop and share recipes for potential protein structures, is one of the earliest scientific discovery games.[132] Two *Foldit* designers also created *Eterna*, a digital game where players design synthetic RNA.[133] In both games, players use interactive tools to manipulate molecules that serve as game pieces. In *Eterna*, the strongest designs are then tested empirically in research labs. Unlike other models of crowdsourced science, not every *Foldit* or *Eterna* player makes a valid contribution to science. Instead, the model is designed so that a game interface draws in a large number of non-traditional contributors (*Foldit* had 240,000 registered players in January of 2012),[134] including a select few that display exceptional skills.[135] The best of these learn the logic of proteins through game play (figure 12), and make scientific contributions as their domain expertise grows.

Evidence of impact

Foldit players can generate better protein structures than state-of-the-art modeling software, and successfully identified a protein critical for the reproduction of the AIDS virus.[136] In addition to supporting groundbreaking biomedical research, *Foldit* and *Eterna* exemplify how serious games can recruit, train, and engage citizens in mass collaboration. Therefore, *Foldit* and *Eterna* also contribute to science by creating a large group of volunteers willing to experiment with different scientific discovery games.[137] To this end, the designers of *Eterna* are partnering with Public Broadcasting Service (PBS) Nova to explore how scientific discovery games can be used in formal education to engage students, support science and technology education, and contribute to scientific research.[138]

Barriers to success

The original *Foldit* was a complex, heavyweight program that required frequent updates and was hosted on a single computer, requiring early volunteers to download the program before

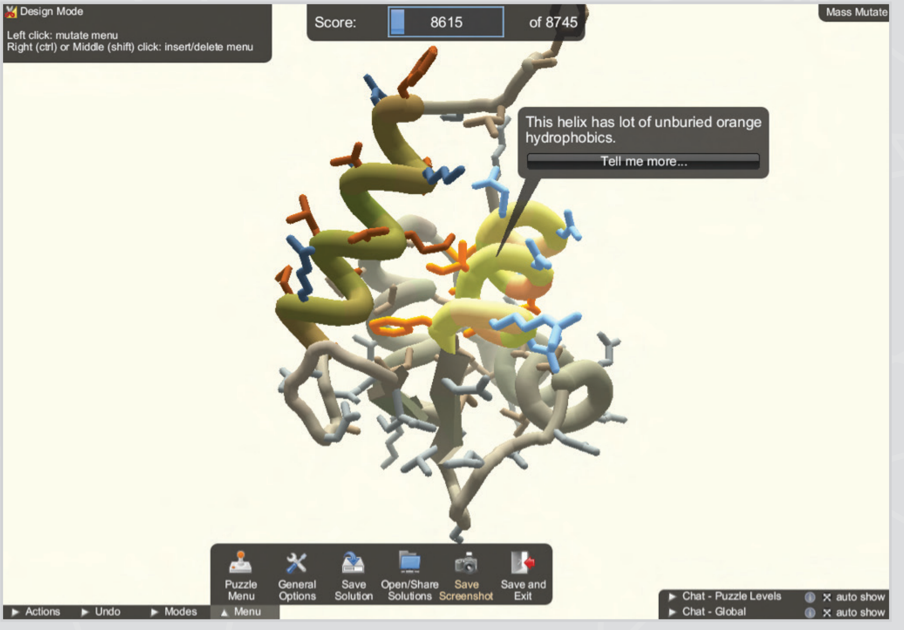


Figure 12. This image displays a Foldit introductory tutorial puzzle. These introductory puzzles are designed to teach players the tools and techniques they need in order to fold proteins. After completing tutorial puzzles, players gain access to Science puzzles that can generate new knowledge.

Name:	Eterna
Description:	Players propose designs for synthetic RNA; the best of these are tested in research labs
Since:	2010
Fields:	Public Health
Sponsors:	National Institute of Health (NIH); NSF; Stanford Bio-X; Media X
Website:	http://eterna.cmu.edu

Name:	Foldit
Description:	A digital multi-player folding game
Since:	2008
Fields:	Public Health
Sponsors:	University of Washington; Defense Advanced Research Projects Agency (DARPA); NSF; NIH; Howard Hughes Medical Institute; Microsoft; Adobe
Website:	http://eterna.cmu.edu

they could play the game. In contrast, *Eterna* is a lightweight program with a streamlined interface hosted by external servers. These simplifications make it easier for volunteers to play the game and for third parties to distribute it; a shortened version of *Eterna* was recently embedded in the website of the *New York Times*.[139] In some cases, the improvements to *Eterna* resulted from outsourcing coding and certain elements of design to processionals instead of relying on the efforts of graduate students and scientific researchers. In other cases, the creators simply drew on previous experience to create a better game.

13

Did You Feel It? and Twitter Earthquake Detection

Citizen seismology for earthquake monitoring

Background

Earthquakes are typically detected by seismometers, sensors linked to a network of computers. In the United States, The United States Geological Survey's (USGS) Advanced National Seismic System (ANSS) coordinates a nationwide network of more than 7,000 sensors and 100 stations that collect valuable real-time seismology data.[140] In some regions, such as the earthquake-prone state of California, these networks are sufficiently dense to provide data for rapid and accurate earthquake detection. However, other areas around the world—such as remote or offshore locations—enjoy significantly less coverage. In these zones, it can take the USGS up to twenty minutes to detect an earthquake and issue a public alert.[141]

Improvement through innovation

Citizen seismology describes how systems of earthquake detection and alerts can be supported by public volunteers. USGS focuses its citizen seismology initiatives at three key points: rapid detection of earthquakes, collecting information for emergency response teams, and information dissemination. One program, Did You Feel It? (DYFI?), asks volunteers who experience earthquakes to fill out a brief online form about their location and shaking intensity.[142] This information is converted to a real-time map hosted on the USGS website, allowing for the public and responders to witness the distribution of shaking from an earthquake (figure 13). The Tweet Earthquake Dispatch (TED) algorithm mines Twitter to detect large increases in the term earthquake in several languages. Once the algorithm detects a spike in these tweets and the event has been verified by instrument readings, the USGS Twitter account posts a tweet with the earthquake magnitude, location, origin time, and link to the USGS website.[143] Thus, TED utilizes user-generated content from Twitter to produce a key service, and pushes information back to the public through the same medium.

Evidence of impact

DYFI? has received more than 2,790,000 total responses since it began soliciting data in 1997.[144] These data augment traditional USGS sensor networks to provide comprehensive coverage across the United States. Through data mining of user-generated content, automated processes such as TED are able to detect earthquakes from around the world and notify seismologists in less than one minute.[145] In contrast, traditional methods may take between two minutes and twenty minutes to accomplish the same task. The time saved through rapid detection sometimes improves the timeliness of public earthquake information.

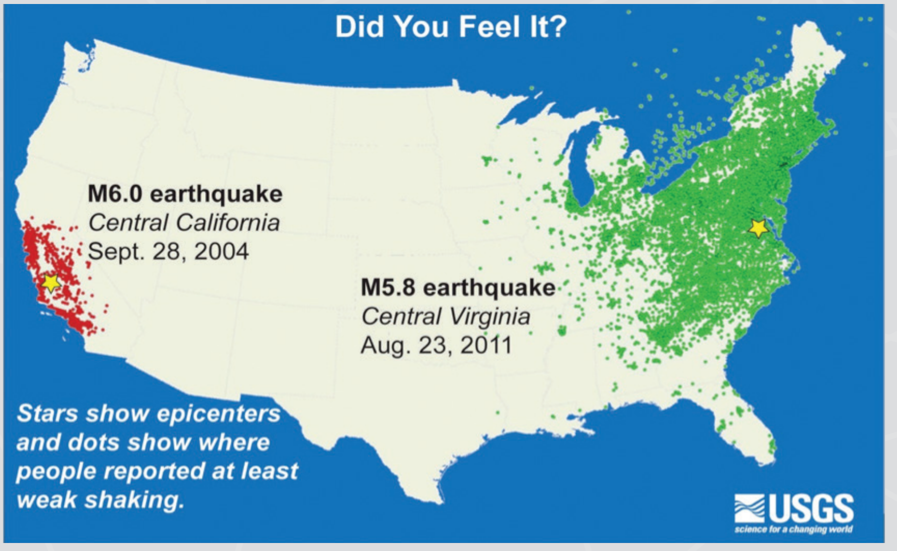


Figure 13. DYFI? data from earthquakes in central California and central Virginia.

Name:	Did You Feel It? (DYFI?)
Description:	Volunteers experiencing an earthquake submit data to USGS, which maps the data in real time
Since:	2004
Fields:	Hazards
Sponsors:	USGS
Website:	http://earthquake.usgs.gov/earthquakes/dyfi/

Name:	Twitter Earthquake Detection (TED)
Description:	An algorithm canvasses Twitter for tweets about earthquakes to aid in early detection
Since:	2009
Fields:	Hazards
Sponsors:	USGS
Website:	http://earthquake.usgs.gov/earthquakes/ted/

Barriers to success

The Privacy Act of 1974 establishes policies and procedures pertaining to the collection, protection, maintenance, utilization, and dissemination or federal records containing personally identifiable information (PII).[146] On Twitter, all Tweets are linked to a username, or the unique identifier of an account holder; in some cases, this username may contain PII such as the full name of the person controlling a Twitter account. When collecting tweets for TED, USGS uses a one-way encryption technique to replace usernames with a different identifier that effectively anonymizes the sender of the Tweet. This technical solution is sufficient to comply with The Privacy Act of 1974.

14

The Advanced Rapid Imaging and Analysis Project

Validating maps for disaster response

Background

The Advanced Rapid Imaging and Analysis (ARIA) project[147] at NASA's Jet Propulsion Laboratory (JPL) and California Institute of Technology is building a system[148] that uses remote sensing, Global Positioning System (GPS), and seismic data to respond to natural disasters. One of the efforts of the project is to use satellite and airborne radar imagery to detect surface changes caused by disasters. Early testing demonstrated the performance of ARIA's algorithm.[149] However, some radar sensors are sensitive enough to detect nontrivial false positives, or data points that highlight changes caused by normal activities.[150] In these cases, a system that uses validation (like through crowdsourcing) supports more efficient emergency response.

Improvement through innovation

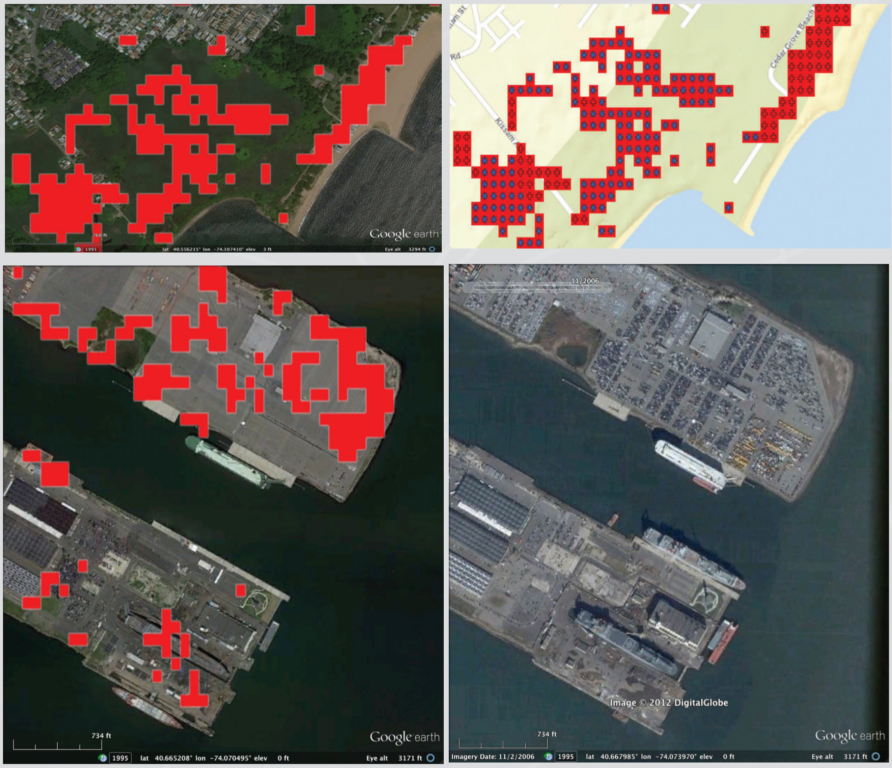
In fall of 2012, Hurricane Sandy wreaked havoc up and down the East Coast. In the days following the hurricane, the Italian Space Agency's radar satellites imaged areas of New York City that were impacted by the storm. When discovering this data set in an online catalog, researchers at ARIA were granted access to the data, and produced a damage proxy map (DPM), where approximately one percent of the total area imaged was marked by red pixels (figures 14 and 15).[151] ARIA then began working with three volunteers from the GISCorps, a network of professional volunteers who work with geographical data, to validate these data points as true damage or false positives. Volunteers were provided with a map consisting of three layers: a map derived from radar data, pre-event satellite photos, and post-event aerial photos taken by NOAA.

Evidence of impact

The three volunteers from the GISCorps validated the mapped data over a four-day period. During this process, a volunteer group that examined 13,721 data points and confirmed 1,139 data points of actual damage—8.3 percent of the total data points in the DPM. False positives fell into two categories. Plants sway in the wind and grow, and so the radar falsely identified some changes in vegetation. Anthropogenic changes, such as the presence or absence of containers on a loading dock, accounted for a second type of false positive data.

Barriers to success

When Hurricane Sandy hit, ARIA had no dedicated staff or system in place to support disaster response. Instead, researchers discovered the data manually, requested access



Name:	The Advanced Rapid Imaging and Analysis (ARIA) Project
Description:	Researchers working on an automated system using radar imagery to detect surface change collaborating with GISCorps volunteers to support disaster response
Fields:	Disaster Response
Sponsors:	NASA's JPL and California Institute of Technology
Website:	Some information is accessible from the JPL website (http://www.jpl.nasa.gov/)

via email, received data through FTP file transfer, and relied on standard phone and email communications with GISCorps volunteers.[152] As a result, the process of securing, processing, and validating data occurred over a period of 15 days—significantly longer than the 48-hour period preferable in disaster response. Latency can be reduced by having a fully operational ARIA system, although rapid quality control challenges still remain. One notable hurdle is bridging the gap between raster and vector data. To this end, ARIA is leveraging a program that supports three students interested in developing automated data conversion tools and an intuitive, usable interface for volunteers. ARIA also identified a need for a global building footprint inventory, prior GIS information that would efficiently exclude false positives in damage proxy maps.

15

Crowdmaps of Development Credit Authority Data

Mapping seed funding in the developing world

Background

USAID's Development Credit Authority (DCA) works with local financial institutions to secure loans for entrepreneurs in the developing world.[153] Established in 1999, the DCA has helped more than 133,000 entrepreneurs secure loans totaling $3.3 billion in capital.[154] In 2012, USAID realizd that mapping the geographic locations of lenders could help aspiring entrepreneurs to identify opportunities for local financing. Unfortunately, DCA records lack a standardized field for reporting location. Instead, due to variations in how geography is reported across the globe, location was collected as free-form text.

Improvement through innovation

Initial manipulation of DCA data suggested that, while 66,917 records could be standardized automatically, 9,607 would require human processing.[155] After weighing a number of alternatives, USAID decided to host a crowdsourcing event to clean and map development loan data on June 1, 2012. This event was attended by established volunteer groups like the GIS corps and Standby Task Force, as well as members of the general public. Volunteers processed all 9,607 records in just 16 hours, 44 hours less than the time USAID allocated for the task. Furthermore, volunteers classified this data at 85 percent accuracy; in comparison, previous attempts at automated processing yielded an accuracy rate of only 64 percent.

Evidence of impact

The event allowed USAID to successfully map guaranteed loan data, providing a valuable resource for entrepreneurs in developing countries and other guarantors. Analysis of loan data also illuminated areas where policies and practices could be improved, illustrating, for example, that only 10 percent of small and medium-size enterprise loans were awarded to female-owned firms. Opening up the loan data not only supports transparency and collaboration, but can also led to better agency policies and practices (figure 16).

Barriers to success

Identifying the acceptable parameters for using crowdsourcing to clean previously non-public information was a necessary precursor to hosting the event.[156] USAID had the

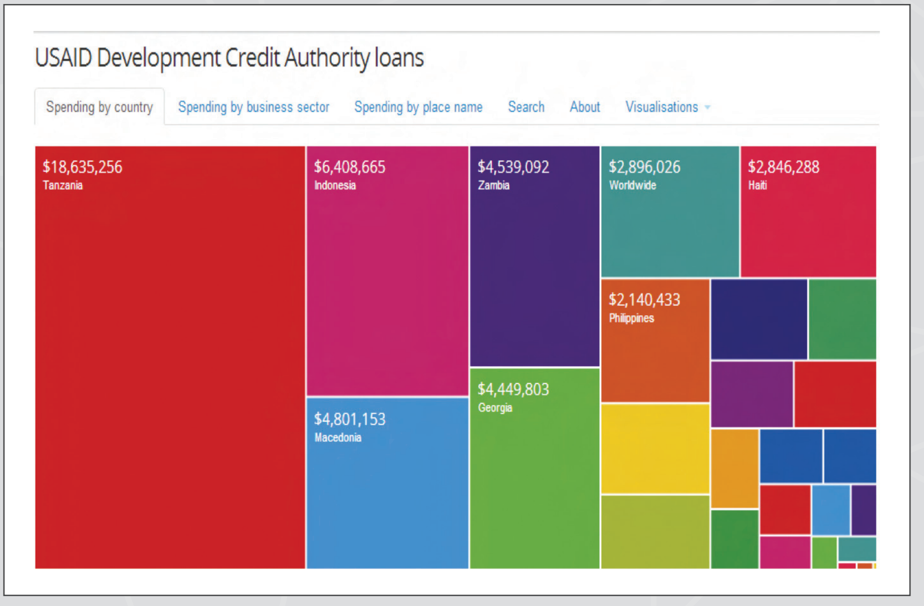


Figure 16. After USAID made the final development credit authority loan data available as open source, a number of people downloaded the data set. This treemap was created and then tweeted back to USAID in order to visualize spending by country.

Name:	Crowdsourcing to Geocode Development Credit Authority Loans
Description:	A crowdsourcing event to clean and map loan data held on June 2013
Since:	2012
Fields:	Development
Sponsors:	USAID
Website:	http://www.usaid.gov/results-and-data/progress-data/data/dca

benefit of precedent: Many other agencies had successfully completed crowdsourcing exercises in the past. For this specific project, USAID encountered challenges with the Non-Disclosure Agreement and the Data Quality Act, as well as using free labor and protecting individuals' personal identifiable information. USAID was able to address all these issues, and wrote a 24-page case study documenting how they did so, in order to help other agencies interested in following suit.[157] In the end, USAID was able to complete the entire project at no additional cost to the federal government.

16

National Broadband Map

How connected is my community?

Background

Broadband, a high-speed telecommunications signaling method, affects education, healthcare, energy management, government management, and public safety by facilitating fast information exchange.[158] As of 2009 more than 100 million homes lacked access, a discrepancy the Federal Communications Commission (FCC) characterized as "the great infrastructure challenge of the early 21st century."[159] Congress passed The Broadband Data Improvement Act in 2008 to improve federal and state data on broadband availability and promote the spread of affordable broadband in all parts of the United States.[160] In 2009, Congress issued a mandate charging the FCC with developing a national plan to secure universal American access to broadband.

Improvement through innovation

Given the large goal and a limited timeframe, the FCC used open innovation to facilitate timely planning and implementation. A Notice of Inquiry posted in April 2009 led to thirty-six public workshops with 10,000 attendees who contributed to the National Broadband Plan.[161] The resulting plan was also designed to support volunteer contributions. Volunteers in 10,000 American homes installed a "white box" that automatically measured broadband speed every minute over three months.[162] Other volunteers downloaded a mobile application that conducted automated speed tests. Still others attended Open Developer Day, a single-day event where programmers were invited into the FCC to build applications using agency data.[163]

Evidence of impact

Consumers use the National Broadband Map as a list of local broadband providers, with key details about the up and down speed offered for each provider (figure 17).[164] Researchers use the map to determine which geographies have the fastest internet connections, then compare this information with data on key demographics such as race and income to study the changing digital divide. Policymakers use map data to target specific areas, such as rural communities, with lowest access to broadband. For example, the Connect America Fund offers up to $4.5 billion in annual support to areas struggling to improve broadband connectivity.[165] Recipients demonstrate need for these funds through National Broadband Map data.

Barriers to success

The Paperwork Reduction Act (PRA) was designed to minimize information burdens to agencies and the public. According to the PRA, agencies who wish to collect new types of

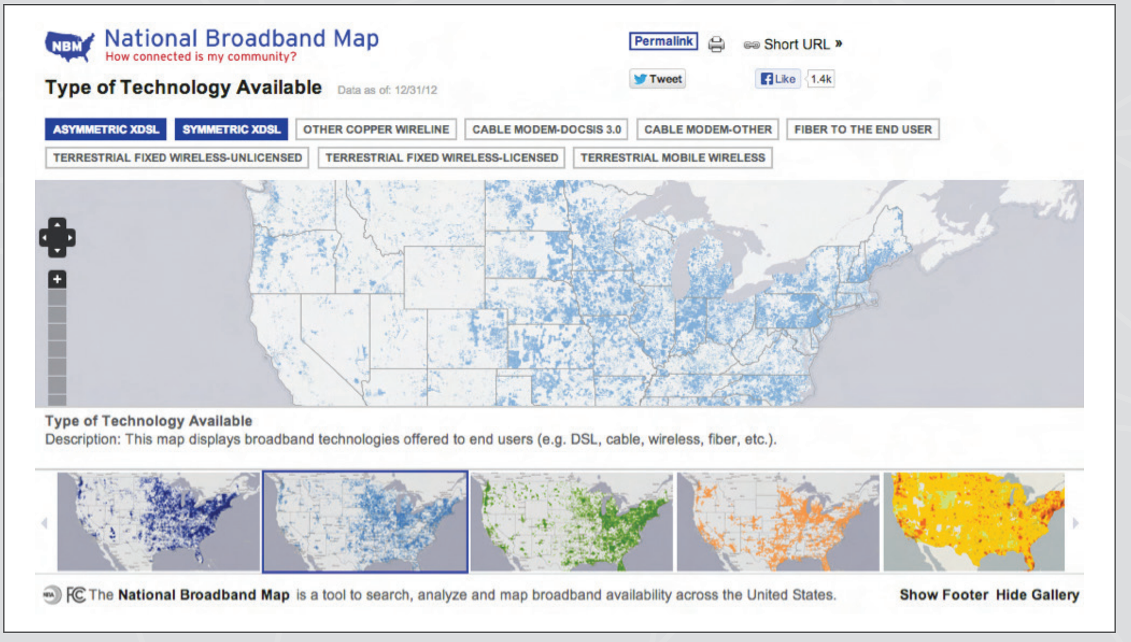


Figure 17. The National Broadband Map interface allows users to manipulate open source data on broadband connectivity.

Name:	The National Broadband Map
Description:	An open innovation project designed to map broadband connectivity across the United States
Since:	2009
Fields:	Telecommunications
Sponsors:	FCC
Website:	http://www.broadbandmap.gov

information must first take measures such as submitting an Information Collection Request to the White House Office of Management and Budget (OMB) and publish a notice in the *Federal Register*.[166] These requirements marked the PRA as a significant administrative hurdle for agencies hoping to start projects in open innovation. In response to concerns vocalized by the Open Government Directive, the OMB issued a 2010 Memorandum on *Social Media, Web-Based Interactive Technologies, and the Paperwork Reduction Act.* This memorandum clarifies where PRA exemptions exist for agencies that use web-based technologies to support open government.[157] Relying on this information helped support open innovation in the FCC and can be used by other agencies as well.

17

The Open PV Project

Mapping the solar photovoltaic market

Background

Photovoltaic (PV) systems capture usable energy from the sun in a "clean" process that emits no pollution, generates no greenhouse gasses, and depletes no fossil fuels.[168] Unfortunately, the technologies that support these systems are expensive to produce, and systems typically run for 1-4 years before installation costs are offset.[169] Furthermore, consumers hoping to install own PV systems have little information about how these systems work in their own communities. The Open PV project is a community-driven database of solar PV installations that is designed to bring this data to private consumers, researchers, and policymakers across the United States.

Improvement through innovation

Consumers who install PV systems submit data to Open PV through four required fields: date installed, size or capacity of the PV installation, location, and total installed cost before incentives.[170] Optional fields include module brand, inverter manufacturer, incentive amount, and market segment (Residential / Commercial / Utility). Governments, PV installers, and utility companies also submit their data in bulk.[171] This dataset reveals broad geographic and historical trends. The Open PV "Market Mapper" is a dynamic web application that allows viewers to map aggregate data based on metrics like the number of total installs or average cost per watt (figure19). The "Installations over Time" visualization displays national installations of PV systems from 2000 to the present.[172] Users also can search through 238,108 records by state, zip code, size, or contributor to view data on specific instillations.

Evidence of impact

Open PV data generates a baseline understanding of which PV systems are purchased and installed in different geographic communities. Consumers use this data to understand which PV systems are most effective in their specific area.[173] This gives buyers confidence that the systems they purchase will work. After implementing new incentives such as tax credits or rebates, decision-makers can compare the resulting number of systems purchased with baseline data to evaluate the effectiveness of their policies. Open PV is also exploring how modeling data can be used to assess the impacts of proposed policies prior to their implementation.[174] Finally, data can summarize the historical trends of a poorly understood market. *Tracking the Sun VI,* a report issued by Department of Energy, National Renewable Energy Laboratory (NREL), and the Lawrence Berkeley National Laboratory, uses data collected in cooperation with Open PV to demonstrate that, while installation prices have fallen drastically from 1998 to 2012, a similar drop in tax rebates and performance incentives also has occurred.[175]

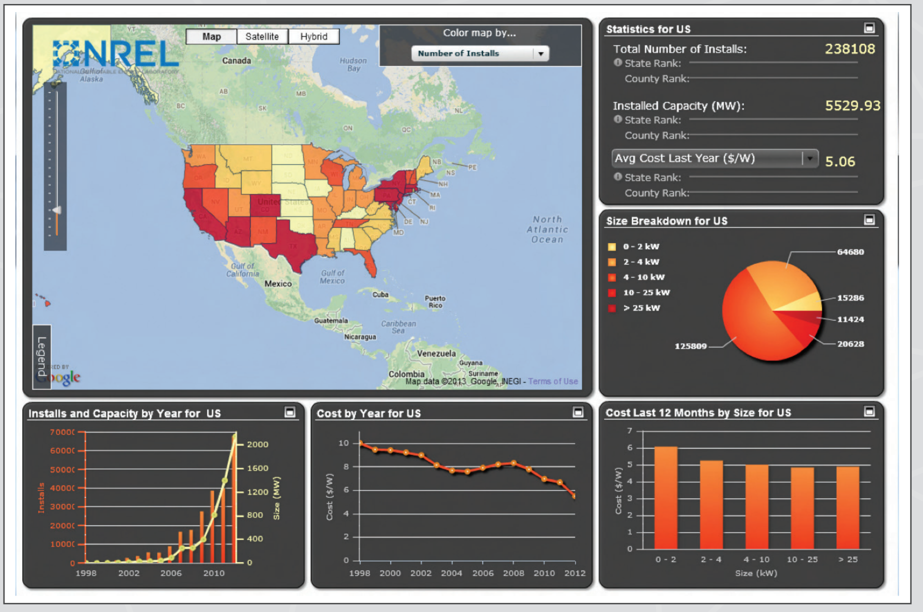


Figure 19. The Open PV Visualziation Gallery allows users to interactively explore the Open PV database. This visualization, the Market Mapper, provides a snapshot of the PV market in different areas of the US, and summarizes key temporal data.

Name:	The Open PV Project
Description:	A collaborative effort between government, industry, and the public to develop a comprehensive database of photovoltaic installations in the USA
Since:	1998
Fields:	Energy
Sponsors:	NREL; DOE
Website:	http://openpv.nrel.gov

Barriers to success

Consumers do not always enter their data with 100 percent accuracy. Open PV initially relied solely on interns to manually check submissions and clean data sets, a labor-intensive process that was quickly supplemented by a technical solution that performs automated checks.[176] Open PV also implemented a “flag” button, allowing users who identify inaccurate data point to alert system administrators. Letting users flag potentially inaccurate data provides an additional source of quality control, but also allows users to channel their frustration into concrete actions that benefit the system as a whole.[177] This legitimizes both the data set and the method of supporting user-generated content.

Discussion

When the phrase "citizen science" entered the vernacular in the early 1990s, it came from two very different sources. Researchers at the Cornell Lab of Ornithology used the term to describe a process where volunteers observe birds as a hobby (1994), but also share their data with biologists conducting scientific research.[178] Notably, the activities of these citizen scientists are generally limited to collecting data for projects designed by professional scientists.

The same phrase is used as the title of a book published in the United Kingdom by Alan Irwin in 1995. [179] In Irwin's version of citizen science, professional researchers "assist the needs and concerns of citizens" by drawing on knowledge possessed or developed by citizens themselves. This definition evokes a scientific paradigm where research conducted by professional scientists is deeply connected with the needs and activities of the public communities that science serves.

Words can be divisive, or they can establish shared understandings. Some writers reconcile these views by characterizing citizen science as a spectrum of projects with different levels of public participation. One group classifies projects according to how involved volunteers are in different steps of the scientific research process, characterizing "contributory" projects as those where the public collects samples or records data, and "collaborative" or "co-created" projects as those where the public also analyzes data or disseminates results.[180] Others consider how much the cognitive abilities of volunteers are utilized in their participation, noting that some projects use citizens as sensors, while others consider them interpreters or even collaborators.[181]

No single model of participation fits every situation. Projects in volunteered computing, such as SETI@Home,[182] require minimal involvement and limited cognitive effort, yet make huge contributions to scientific research. With that said, the projects that report impacts beyond the advancement of scientific research—such as a volunteer's increased knowledge of the scientific process, or enhanced community engagement—are usually the projects that involve volunteers more deeply in the process of scientific research. In extreme levels of collaboration, these projects may even have the ability to challenge social norms, including the underlying distinction between "citizens" and "scientists." Following the work of Alan Irwin in the United Kingdom, there is an opportunity and a need to expand the role that citizen science can play in public decision making and. Citizen science can be a remarkably democratic process with the potential to transform the way local knowledge is created, understood, and used.

Glossary

Working Definitions, November 2013

Citizen Science is a form of collaboration where members of the public participate in scientific research to meet real world goals. The value of citizen science for producing scientific data and educating volunteers is well-established. Citizen science is also considered a paradigm where the needs and activities of an engaged public are intertwined with professional scientific research. Related terms include public participation in scientific research, volunteer monitoring, crowdsourced science, democritized science, and participatory action research.

Crowdmapping, also called Volunteered Geographic Information, is a process where public volunteers create, assemble, and distribute geographic knowledge. Contributors to VGI projects may be volunteers who submit or modify data hosted by open-source mapping platforms, such as OpenStreetMap.[183] Related terms include, but are not limited to, neogeography, counter-mapping, participatory mapping, participatory geoweb, and public participation geographic information systems (PPGIS).

Crowdsourcing is a process where individuals or organizations solicit contributions from a large group of unknown individuals ("the crowd") or, in some cases, a bounded group of trusted individuals or experts. Contributors to crowdsourcing projects may or may not be domain experts, and may or may not be paid for their efforts. Crowdsourcing often occurs online, and employs a piecemeal approach where different individuals contribute small portions to a final project or product ("microtasking").

Do-It-Yourself (DIY) is a method of creating, modifying, or repairing something without the aid of professional experts. People who start DIY projects do so because of economic reasons, or due to creative impulses. A number of communities, both online and offline, join DIY experts together. In science, these communities include DIYBio[184] and FAB Lab.[185]

A **Hackathon** is a model of mass collaboration where volunteer software developers create new technologies such as mobile applications, often for a prize or other reward. Hackathons usually take place over a set time frame, such as a single weekend. Sponsors of hackathons benefit from the technologies produced, while participants are motivated by prizes, access to sponsors, and community participation.

In **Mass Collaboration**, individuals work together to achieve a shared goal. In contrast to forms of collaboration such as cooperation, mass collaboration does not require contributors to develop a shared understanding of different processes. Instead, independent efforts are aggregated to create a complete solution.

Open Data is the ideal that data and other types of knowledge should be shared by governments, organizations, and the public "in ways that make the data easy to find, accessible, and usable." [186] Open data supports public participation in innovation and the scientific process, and the production of new knowledge.

Open Innovation is a paradigm that suggests that organizations can and should solicit contributions from external volunteers. These outsiders share unique perspectives, generate new knowledge and technology, or otherwise bolster organizational resources. Open innovation is implemented through approaches such as mass collaboration, crowdsourcing, citizen science, or prizes and challenges.

Open Science is a solicitation to share the process or results of scientific inquiry with a broad community. Historically, open science was a call for academics to publish their research in peer-reviewed journals, thus making their results available to both members of the scientific community and to an interested public.[187] The term is more recently understood as a call for transparency of research methods, or for open-source data.

Open Source is a product development model that supports both universal access and universal re-distribution. Open source typically refers to the production of computer software code, which may be developed individually and then shared, or developed collaboratively by many programmers. Open source software development is considered an early success story of distributed collaboration.

Participatory sensing is a model of data collection where volunteers gather, analyze, and share local knowledge collected through sensors.[188] Sensors may be stationary or portable. They may be integrated with GPS and wifi-enabled technology either directly (as with smartphones) or as add-ons through an app. Participatory sensing can collect data about an individual, but most commonly collects data about an individual's environment. Related terms include community sensing and remote sensing.

For **Prizes and challenges,** prize competitions stimulate innovation through incentives, which can be monetary rewards or non-cash rewards like recognition.[189] Benefits to sponsors of prize competitions include paying only for results, exploring a wide breadth and depth of potential solutions, targeting an ambitious goal without predicting which team or approach is most likely to succeed, reaching beyond usual suspects to tap top talent, and bringing out-of-discipline perspectives to bear. Challenges use a focused problem-statement approach to obtain solutions or stimulate innovation from a broad and sometimes undefined public, often in the absence of external reward.

Notes

1 Henry Chessbrough, Open Innovation: The New Imperative for Creating and Profiting from Technology (Boston: Harvard Business School Publishing Company: 2003).

2 See http://www.whitehouse.gov/sites/default/files/omb/assets/memoranda_fy2009/m09-12.pdf.

3 See http://www.whitehouse.gov/sites/default/files/omb/memoranda/2013/m-13-13.pdf.

4 See http://www.whitehouse.gov/sites/default/files/docs/preview_report_of_open_gov_national_action_plan_10_30.pdf

5 Audubon. "History of the Christmas Bird Count." Accessed October 3, 2013. http://birds.audubon.org/history-christmas-bird-count.

6 Audubon. "Christmas Bird Count of Scientific Articles." Accessed October 3, 2013. http://birds.audubon.org/christmas-bird-count-bibliography-scientific-articles.

7 See http://horseshoecrabsurvey.com/.

8 See http://www.globe.gov/.

9 See http://www.zooniverse.org.

10 Firas Khatib, Frank DiMalo, Foldit Contenders Group, et al., "Crystal structure of a monomeric retroviral protease solved by protein folding game players," Nature Structural & Molecular Biology 18 (2001), 1175-1177.

11 Privacy Act of 1974, 5 U.S.C. §552a (2000).

12 Paperwork Reduction Act of 1980, 44 U.S.C. §3501-3521.

13 Chris Lintott, Kevin Schawinski, Anze Slosar, et al., "Galaxy Zoo: morphologies derived from visual inspection of the Sloan Digital Sky survey," MNRAS 389.3 (2008), 1179-1189.

14 Zachary Bastian and Michael Byrne, The National Broadband Map: A Case Study on Open Innovation for National Policy, Washington, DC: Woodrow Wilson International Center for Scholars, 2012.

15 The EPA. "Our Mission and What We Do." Accessed September 10, 2013. http://www2.epa.gov/aboutepa/our-mission-and-what-we-do/.

16 French, Rebecca. Interview by author. E-mail. September 9, 2013.

17 The EPA. "Equipment Loan Program for Volunteer Water Monitoring." Accessed September 30, 2013. http://www.epa.gov/region1/lab/volmonequiploan.html.

18 French, Rebecca.

19 The EPA, "Environmental Justice and Small Grants Program," Accessed September 30, 2013, http://www.epa.gov/environmentaljustice/grants/ej-smgrants.html.

20 "EPA's Volunteer Monitoring Program."

21 The EPA, "Tonawanda Community Air Quality Study, Accessed September 30, 2013, http://www.dec.ny.gov/chemical/59464.html.

22 The EPA. "The Volunteer Monitor's Guide To Quality Assurance Project Plans." Accessed September 10, 2013. http://water.epa.gov/type/rsl/monitoring/qappcovr.cfm/.

23 "EPA's Volunteer Monitoring Program."

24 Communication with Rebecca French and Alice Mayio.

25 See http://www.epa.gov/storet/.

26 Delaware Riverkeeper Network, "Ongoing Issues: Horseshoe Crabs," Accessed September 19, 2013, http://www.delawareriverkeeper.org/river-action/ongoing-issue-detail.aspx?Id=30.

27 Michels, Stewart. Interview by author. Phone and email. September 19, 2013.

28 Atlantic States Marine Fisheries Commission, "Interstate Fishery Management Plan for the Horseshoe Crab," Accessed September 20th, 2013, http://www.asmfc.org/.

29 ASMFC. "About Us." Accessed September 20th, 2013. http://www.asmfc.org/aboutus.htm.

30 See http://www.asmfc.org/horseshoeCrab.htm.

31 Horseshoe Crab Survey Information. "2013 Survey Dates and Times." Accessed September 22, 2013, http://www.horseshoecrabsurvey.com/pdf/2013surveydates.pdf.

32 Michels, Stewart.

33 Ibid.

34 "Interstate Fishery Management Plan for Horseshoe Crab."

35 Atziri Ibanez. "Citizen Science Programs at NOAA's National Estuarine Research Reserve System." 2013.

36 Michels, Stewart.

37 Ibid.

38 Emily Holt and Scott Milller, "Bioindicators: Using organisms to measure environmental impacts," *Nature Education Knowledge*, 10 (2008), Available online from http://www.nature.com/scitable/knowledge/library/bioindicators-using-organisms-to-measure-environmental-impacts-16821310.

39 Chris Bowser, Sarah Mount, Zoraida Maloney, et al. The Hudson River Eel Project. New York State Department of Environmental Conservation. Albany: 2013.

40 Bowser, Chris. Interview by author. Phone. September 16, 2013.

41 Ibid.

42 Ibid.

43 Ibid.

44 Nolan Doesken and Thomas McKee. "An Analysis of Rainfall for the July 28, 1997 Flood in Fort Collins, Colorado." Accessed October 18, 2013. http://ccc.atmos.colostate.edu/~odie/rain.html.

45 Doesken, Nolan. Interview by author. Phone. October 17th, 2013.

46 Nolan Doesken and Henry Reges, "The Value of the Citizen Weather Observer," *WeatherWise* (November/December 2010): 30-38.

47 Doesken, Nolan.

48 "The Value of the Citizen Weather Observer."

49 Doesken, Nolan.

50 Ibid.

51 GLOBE. "Globe Investigations." Accessed October 28, 2013. http://www.globe.gov/explore-science/globe-investigations.

52 GLOBE. "Become a GLOBE partner." Accessed October 28, 2013. http://www.globe.gov/join-globe/become-a-globe-partner

53 Murphy, Tony. Interview by author. Phone. September 5, 2013.

54 Ibid.

55 Melissa Consuelo Perez, Ingrid Rodriguez Leon, and Elia Nancy Rodriguez Navar, "Absorption and scattering of aerosols related with its effects over the population's respiratory system in the Guadalajara Metropolitan Area (GMA)" (paper presented at the IEEE International Geoscience and Remote Sensing Symposium, Munich, 22-27 July, 2012).

56 For summaries of evaluations from Alabama's Program, which includes GLOBE as part of its statewide science program, see: http://www.amsti.org/About/Evaluations/tabid/133/Default.aspx

57 Children's Online Privacy Protection Act, U.S. Code 15 (1998), §§ 6501–6506.

58 Murphy, Tony.

59 Mark Schwartz, Julio Betancourt, and Jake Weltzin, "From Caprio's lilacs to the USA National Phenology Network," *Frontiers in Ecology*, 10.6 (2012), 324-327.

60 Nature's Notebook. "Why Observe?" Accessed September 11th, 2013. https://www.usanpn.org/nn/why-observe. .

61 "From Caprio's lilacs to the USA National Phenology Network."

62 Ibid.

63 Su-Jong Jeong, David Medvigy, and Elena Shevilakova, et al., "Predicting changes in temperate forest budburst using continental-scale observations and models," *Geophysical Research Letters*, 40 (2013), 1-6.

64 Tony Ault, Geoffrey Henebry, Nathan Kraft,et al., "The False Spring of 2012, Earliest in North American Record," *Eos*, 94.20 (2013), 181-182.

65 Weltzin, Jake. Interview by author. Phone and email. September 11th, 2013.

66 "The False Spring of 2012, Earliest in North American Record."

67 Weltzin, Jake.

68 Crimmins, Theresa. Interview by author. Phone and email. September 13, 2013.

69 Ibid.

70 Brian Sullivan, Chris Wood, Marshall Illiff, et al., "eBird: A citizen-based bird observation network in the biological sciences," *Biological Conservation*, 142 (2009), 2282-2292.

71 Sullivan, Brian. Interview by author. Phone. September 16th, 2013.

72 eBird. "About." Accessed September 23, 2013. http://ebird.org/content/ebird/about/.

73 Jun Yu, Steve Kellling, Jeff Gerbracht., et al., "Automated data verification in a large-scale citizen science project: A case study," In Proc. of 2012 IEEE 8th International Conference on E-Science (2012), 1-8.

74 Sullivan, Brian.

75 eBird. "View and Explore Data." Accessed September 23, 2013. http://ebird.org/ebird/eBirdReports?cmd=Start.

76 "About."

77 Sullivan, Brian.

78 Ibid.

79 State of the Birds, "USDA and DOI Highlight Successes of Protecting Bird Habitat on Private Lands," Accessed September 26, 2013, http://www.stateofthebirds.org/Press%20Release%2007-02-13%20State%20of%20Birds%20-%20FINAL%20%281%29.pdf.

80 Chris Wood, Brian Sullivan, Marshall Iliff, et al., "eBird: Engaging Birders in Science and Conservation," *PLOS Biology*, 9.12 (2011).

81 Ibid.

82 Sullivan, Brian.

83 The National Archives, "Our Mission and Vision," Accessed September 13, 2013, http://www.archives.gov/about/info/mission.html.

84 Stewart, Meredith. Interviewed by author. Phone. September 6, 2013.

85 Ibid.

86 AOTUS. "Cultivating Citizen Archivists."¬¬ Accessed September 13, 2013. http://blogs.archives.gov/aotus/?p=144.

87 See http://www.archives.gov/citizen-archivist/.

88 Stewart, Meredith.

89 Ibid.

90 ACUS. "National Archives/ The Citizen Archivist Initiative." Accessed September 13, 2013. http://www.acus.gov/best-practices/success-story/national-archivesthe-citizen-archivist-initiative/.

91 See https://drupal.org/project/transcribe_distribution.

92 Stewart, Meredith.

93 Gordon Bell, Tony Hey, and Alex Szalay, "Beyond the Data Deluge," *Science*, 323.6.9 (2009), 1297-1298.

94 Tony Hey, Stewart Tansley, and Kristin Tolle, Eds., "Jim Gray on eScience: A Transformed Scientific Method," in *The Fourth Paradigm: Data-Intensive Scientific Discovery*, ed. Tony Hey et al. (Redmond: Microsoft Research, 2009), xvii.

95 Zooniverse. "Purpose." Accessed September 13, 2013. https://www.zooniverse.org/about

96 Chris Lintott, Kevin Schawinski, Anze Slosar, et al., "Galaxy Zoo: morphologies derived from visual inspection of the Sloan Digital Sky survey," *MNRAS*, 389, 3 (2008), 1179-1189.

97 Smith, Arfon. Interview with author. Phone. September 5, 2013.

98 Zooniverse. "Moon Zoo." Accessed September 13, 2013. https://www.zooniverse.org/project/moonzoo.

99 See https://www.zooniverse.org/project/oldweather.

100 See https://www.zooniverse.org/project/ancientlives.

101 "Galaxy Zoo: morphologies derived from visual inspection of the Sloan Digital Sky survey."

102 Chris Lintott, Kevin Schawinski, William Kell, et al., "Galaxy Zoo: 'Hanny's Vorwerp', a quasar light echo?," *MNRAS*, 399.1, 129-140.

103 "Galaxy Zoo: morphologies derived from visual inspection of the Sloan Digital Sky survey."

104 Smith, Arfon.

105 Ibid.

106 Ted Greenwald. "35 Innovators under 35." MIT Technology Review. Accessed October 29, 2013, http://www.technologyreview.com/lists/innovators-under-35/2013/visionary/lina-nilsson/.

107 Tekla Labs. "About." Accessed October 25, 2013. http://www.teklalabs.org/about/.

108 Tekla Labs. "Tekla Labs DIY Guide Library." Accessed October 25, 2013. http://guides.teklalabs.org.

109 Ibid, but statistics are only viewable by users who are logged in.

110 Creative Commons, "Attribution- Share Alike 3.0 Unported," Accessed October 29, 2013, http://creativecommons.org/licenses/by-sa/3.0/.

111 Tekla Labs. "Answers." Accessed October 25, 2013. http://guides.teklalabs.org/Answers.

112 Toni Feder, "Facilitating Science in Developing Countries," *Physics Today*, 64.2 (2011), 19-21.

113 Tekla Labs, "About," Accessed October 25, 2013, http://www.teklalabs.org/about/.

114 Nilsson, Lina. Interview by author. Phone. October 23, 2013.

115 See http://www.plos.org/.

116 Tekla Labs. "Flags." Accessed October 29, 2013. http://guides.teklalabs.org/Info/flags.

117 Steven Leckert, "The Hackathon Is On: Pitching and Programming the Next Killer App," Wired, February 17, 2012, accessed September 22, 2013. http://www.wired.com/magazine/2012/02/ff_hackathons/all.

118 Ibid.

119 Zachary Bastian. The Power of Hackathons: A Roadmap for Sustainable Open Innovation (Washington: Woodrow Wilson International Center for Scholars, 2012).

120 NASA. *International Space Apps Challenge 2013 Mission Report* (Washington: NASA, 2013). https://speakerd.s3.amazonaws.com/presentations/91742720aea1013002162ab4f7362367/SpaceApps_MissionReport_WebSingle_NASAVersion.pdf.

121 NASA. "A global collaboration to improve life on Earth and life in space." Accessed September 22, 2013. http://spaceappschallenge.org/.

122 NASA. "Challenges." Accessed September 22, 2013. http://2013.spaceappschallenge.org/challenges/.

123 NASA. "Judging."" Accessed September 22, 2013, http://2013.spaceappschallenge.org/about/judging/.

124 Llewellyn, Allison. Interview by author. Phone. September 6, 2013.

125 Ibid.

126 Ibid.

127 NASA. "Backyard Poultry Farmer." Accessed September 13, 2013. http://2013.spaceappschallenge.org/challenge/backyard-poultry-farmer/.

128 ."The Hackathon Is On: Pitching and Programming the Next Killer App."

129 Llewellyn, Allison.

130 Jane McGonigal, *Reality is Broken*, New York: Penguin Press, 2011.

131 Eterna. "About Eterna." Accessed September 15, 2013. http://eterna.cmu.edu/web/about/.

132 See http://fold.it/portal/..

133 See http://eternal.cmu.edu.

134 Jessica Marshall, "Victory for crowdsourced biomolecular design," accessed September 19, 2013, http://www.nature.com/news/victory-for-crowdsourced-biomolecule-design-1.9872

135 Benjamin Good and Andrew Su, "Games with a scientific purpose," *Genome Biology,* 12 (2011), 135-137.

136 Firas Khatib, Frank DiMalo, Foldit Contenders Group, et al., "Crystal structure of a monomeric retroviral protease solved by protein folding game players," *Nature Structural & Molecular Biology*, 18 (2001), 1175-1177.

137 Treuille, Adrien. Interview by author. Phone. September 6, 2013.

138 Ibid.

139 Ibid.

140 Jason Young, David Wald, Paul Earle, et al. *Transforming Earthquake Detection through Citizen Seismology* (Washington: Woodrow Wilson International Center for Scholars, 2013).

141 Ibid.

142 See http://earthquake.usgs.gov/dyfi.

143 See http://earthquake.usgs.gov/earthquakes/ted.

144 *Transforming Earthquake Detection through Citizen Seismology.*

145 Ibid.

146 See http://www.justice.gov/opcl/privstat.htm.

147 Mark Simons, Susan Owen, Frank Webb, et al., "The ARIA Project: Advanced Rapid Imaging and Analysis for Natural Hazard Monitoring and Response," Presented at the American Geophysical Union Fall Meeting, December 3-7, 2012, San Francisco, CA.

148 Hook Hua, Susan Owen, Sang-Ho Yun, et al., "A Hybrid-Cloud Science Data System Enabling Advanced Rapid Imaging & Analysis for Monitoring Hazards" (paper presented at the American Geophysical Union Fall Meeting, San Francisco, CA, December 3-7, 2012)..

149 Sang-ho Yun, Eric Fielding, Piyjush Agram, et al., "Robust Damage Assessment of Natural Disasters using Radar Interferometry Coherence" (paper presented at the 9th International Workshop on Remote Sensing for Disaster Response, Stanford, CA, September 15-16, 2011).

150 Yun, Sang-Ho. Interview by Author. Phone. October 28, 2013.

151 Sang-Ho Yun, Alessandro Coletta, Eric Fielding, et al., "Satellite Radar and GIS Volunteers Detect Hurricane Sandy Damage," GISCorps of URISA, Sandy response report online at: http://www.giscorps.org/index.php?option=com_content&task=view&id=129&Itemid=63 2012

152 Yun, Sang-Ho.

153 USAID. "Development Credit Authority: Putting wealth to work." Accessed September 15, 2013. http://www.usaid.gov/sites/default/files/documents/1865/usaid_dcareport_gills_3.pdf.

154 Shadrock Roberts, Stephanie Grosser, and Ben Swartley. *Crowdsourcing to geocode development credit authority data: A case study*. Washington: USAID, 2012.

155 Ibid

156 Grosser, Stephanie. Interview with author. Phone. September 3, 2013.

157 *Crowdsourcing to Geocode Development Credit Authority Data: A Case Study.*

158 *The National Broadband Map: A Case Study on Open Innovation for National Policy.*

159 Federal Communications Commission, Connecting America: The National Broadband Plan, Accessed September 30, 2013, http://www.broadband.gov/download-plan/..

160 See http://www.govtrack.us/congress/bills/110/s1492/text. "

161 Connecting America: The National Broadband Plan.

162 Byrne, Michael. Interview by author. Phone. September 12, 2013.

163 *The National Broadband Map: A Case Study on Open Innovation for National Policy.*

164 Anne Neville, "New Broadband Map Data Shows Progress, But Work Remains," NTIA Blog, August 13, 2013, http://www.ntia.doc.gov/blog/2013/new-broadband-map-data-shows-progress-work-remains.

165 FCC. "Connect America Fund & Intercarrier Compensation Reform Order and FNPRM Executive Summary." Accessed October 18, 2013. http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-310692A1.pdf.

166 Ibid.

167 See http://www.white-house.gov/sites/default/files/omb/assets/inforeg/SocialMediaGuidance_04072010.pdf.

168 NREL. *Energy Payback: Clean Energy from PV* (Washington: NREL, 1998).

169 *Energy Payback: Clean Energy from PV*

170 The Open PV project. "About." Accessed September 22, 2013. https://openpv.nrel.gov/about.

171 Dan Getman. Interview by author, Phone. September 12, 2013.

172 The Open PV project. "Open PV Installation Gallery." Accessed September 22, 2013. https://openpv.nrel.gov/gallery.

173 Getman, Dan..

174 Ibid.

175 Galen Barbose, Naim Darghouth, Samantha Weaver, et al. *Tracking the Sun VI: A Historical Summary of the Installed Price of Photovoltaics in the United States from 1998 to 2012* (Berkeley: Laurence Berkeley National Laboratory, 2013).

176 Getman, Dan."

177 Ibid.

178 Rick Bonney, Jennifer Shirk and Tina Phillips "Citizen Science." In: Roberg Gunstone (Ed.), *Encyclopedia of Science Education* (Heidelberg: Springer-Verlag: 2003)..

179 Alan Irwin, *Citizen Science: A Study of People, Expertise and Sustainable Development* (New York: Routledge: 1995).

180 Rick Bonney, Heidi Ballard, Rebecca Jordan, et al. *Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education* (2005). Center for Advancement of Informal Science Education (CAISE): Washington, DC.

181 Muki Haklay, "Citizen Science and Volunteered Geographic Information: Overview and Typology of Participation," in *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice,* Edited by Daniel Sui, Sarah Elwood, and Michael Goodchild (Berlin: Springer, 2013), 105-122.

182 See http://setiathome.berkeley.edu/.

183 See http://www.openstreetmap.org/#map=5/51.500/-0.100.

184 See hhttp://diybio.org/.

185 See http://fab.cba.mit.edu/.

186 See http://www.whitehouse.gov/the-press-office/2013/05/09/executive-order-making-open-and-machine-readable-new-default-government-

187 Paul David, "Understanding the Emergence of 'Open Science' Institutions: Functionalist Economics in Historical Context," *Industrial and Corporate Change*, 13 (2004), 571-589.

188 Jeff Burke, Deborah Estrin, Mark Hansen, et al. "Participatory Sensing," Paper presented at *The International Workshop on World Sensor Web*, Boulder, Colorado, October 31st, 2006.

189 The White House Office of Social Innovation and Civic Participation. "Prizes and Challenges." Accessed September 10, 2013. http://www.whitehouse.gov/administration/eop/sicp/initiatives/prizes-challenges/.

Wilson Center

One Woodrow Wilson Plaza
1300 Pennsylvania Avenue, N.W.
Washington, DC, USA 20004-3027
202-691-4000
www.wilsoncenter.org

COMMONS LAB

The Commons Lab of STIP advances research and policy analysis of emerging technologies and methods—such as social media, crowdsourcing, and volunteered geographic information—that empower individuals ("citizen sensors") to collectively generate actionable scientific data, to augment and support disaster response and recovery, and to provide input to government decision-making, among many other activities.

http://CommonsLab.wilsoncenter.org

The Commons Lab is supported by the Alfred P. Sloan Foundation.