EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
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MEMORANDUM TO THE HEADS OF EXECUTIVE DEPARTMENTS AND AGENCIES

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SUBJECT: Addressing Societal and Scientific Challenges through Citizen Science and Crowdsourcing

Overview

Through citizen science and crowdsourcing, the Federal Government and nongovernmental organizations engage the American public in addressing societal needs and accelerating science, technology, and innovation. In ***citizen science,*** the public participates voluntarily[1] in the scientific process, addressing real-world problems in ways that may include formulating research questions, conducting scientific experiments, collecting and analyzing data, interpreting results, making new discoveries, developing technologies and applications, and solving complex problems.[2] In ***crowdsourcing***, organizations submit an open call for voluntary assistance from a large group of individuals for online, distributed problem solving.

Citizen science and crowdsourcing projects can enhance scientific research and address societal needs, while drawing on previously underutilized resources. For example, after analyzing 338 citizen science biodiversity projects around the world, researchers at the University of Washington estimated that the in-kind contributions of 1.3–2.3 million citizen science volunteers to biodiversity research have an economic value of up to $2.5 billion per year.[3] Other benefits include providing hands-on learning in science, technology, engineering, and mathematics (STEM), and connecting members of the public directly to Federal agency missions and to each other. In recognition of these potential benefits, this memorandum encourages the use, where appropriate, of citizen science and crowdsourcing by Federal agencies.

Specifically, this memorandum:

i. Outlines principles that agencies should apply in order to ensure future use of citizen science and crowdsourcing in a way that is appropriate and leads to greatest value and impact;
ii. Directs agencies to take two specific steps to advance appropriate application of these methods:

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[1] In both citizen science and crowdsourcing, voluntary participation can be active or passive depending on the nature of the project.
[2] This definition should not be interpreted to imply that research projects that incorporate volunteers as "subjects" of the research are citizen science projects.
[3] Theobald, E.J., A.K. Ettinger, H.K. Burgess, L.B. DeBey, N.R. Schmidt, H.E. Froehlich, C. Wagner, J. HilleRisLambers, J. Tewksbury, M.A. Harsch, and J.K. Parrish. 2014. Global change and local solutions: Tapping the unrealized potential of citizen science for biodiversity research. Biological Conservation 181: 236-244. doi:10.1016/j.biocon.2014.10.021

a. identify an agency coordinator for citizen science and crowdsourcing projects; and
b. catalog agency-specific citizen science and crowdsourcing projects on a government-wide online database and website — to be developed by the General Services Administration (GSA) — in order to make these projects easier for the public to discover, to help improve collaboration within and across agencies, and to reveal opportunities for new projects;

iii. Recommends agency actions to build capacity for citizen science and crowdsourcing; and

iv. Provides, in the Appendix, examples of successful completed and ongoing applications of citizen science and crowdsourcing at Federal agencies.

Principles for Effective Use of Citizen Science and Crowdsourcing

Citizen science and crowdsourcing projects should contribute directly to a goal or need relevant to the mission of each agency. Office of Management and Budget (OMB) Memorandum M-15-16, Multi-Agency Science and Technology Priorities for the FY 2017 Budget, encourages Federal agencies to consider incorporating citizen science and crowdsourcing into their programs, as appropriate. To use citizen science and crowdsourcing appropriately and effectively, agencies should apply the following principles, where relevant, in project design:

- *Data quality*. Information collected and/or used by volunteers should be credible and usable. Recognizing that a "one-size-fits-all" quality-assurance approach will not work for all projects, Federal agencies should apply the principle of "fitness for use,"[4] ensuring that data have the appropriate level of quality for the purposes of a particular project. In addition, citizen science projects should incorporate the same practices generally followed by all science projects, including data-quality assurance, data management, and ongoing project evaluation;[5] relevant Federal and agency policies for scientific integrity and ethics; and other applicable agency principles, policies, and practices.
- *Openness*. Information is a valuable national resource and a strategic asset to the Federal Government, its partners, and the public. Data worth collecting and using also are worth preserving and sharing. Federal agencies should design projects that generate datasets, code, applications, and technologies that are transparent, open, and available to the public,[6] consistent with applicable intellectual property, security, and privacy protections. Agencies should use machine-readable formats to share data, metadata, and results with project volunteers and the general public.[7]
- *Public participation*. Public engagement enhances the Government's effectiveness and improves the quality of its decisions. Americans' collective expertise and information are valuable assets. Participation in projects should be fully voluntary, and volunteers should be acknowledged for their contributions. Further, volunteers should know how

[4] Fitness for use means the degree to which a dataset is suitable for a particular application or purpose, encompassing factors such as data quality, scale, interoperability, cost, and data format.
[5] Office of Management and Budget. 2013. Open data policy: Managing information as an asset. Memorandum, May 9. Washington, DC.
[6] IBID.
[7] Office of Science and Technology Policy. 2013. Increasing access to the results of federally funded scientific research. Memorandum, February 22. Washington, DC.

their contributions are meaningful to the project and how they, as volunteers, will benefit from participating. Where appropriate, agencies should consider engaging other countries or regions with relevant experience, programs, or citizenry to provide useful scientific data on issues that span national borders and build international understanding of shared scientific challenges.

Improving the Strategic Use of Crowdsourcing and Citizen Science

To apply the principles outlined above and improve the strategic use of crowdsourcing and citizen science, Federal agencies shall:

- *Improve coordination of and support for citizen science and crowdsourcing within and between agencies*. Within 60 days of the issuance of this memo, each agency shall identify an agency coordinator for citizen science and crowdsourcing projects on that agency's Open Government website. The coordinator will manage the agency's contributions to a public database of Federal citizen science and crowdsourcing projects, to be developed by GSA (see below). To increase interagency coordination, the coordinator will work with both the White House Office of Science and Technology Policy (OSTP) and other Federal agencies through the Federal Community of Practice for Crowdsourcing and Citizen Science (CCS), the National Science and Technology Council (NSTC), and other interagency working groups, as appropriate, to participate in future policy-development discussions on this subject. In addition, the agency coordinator could, as appropriate, seek strategic areas of opportunity for applying citizen science and crowdsourcing to meet agency goals; serve as an agency-wide resource for citizen science and crowdsourcing; build awareness of citizen science and crowdsourcing projects both within the agency and with agency partners; and work to overcome administrative and policy barriers to citizen science and crowdsourcing within the agency.
- *Contribute to a public database of Federal citizen science and crowdsourcing projects*. Within 180 days of the issuance of this memo, each agency shall catalogue the citizen science and crowdsourcing activities it directly supports that are open for public participation. The purpose of the catalogue is to make it easier for volunteers to find out about projects they can join, improve cross-agency collaboration, and reveal opportunities for new high-impact projects. In collaboration with OSTP and the CCS, each agency shall provide data to GSA about the activities it directly supports in a form consistent with GSA requirements; within 90 days of the issuance of this memo, OSTP, GSA, and CCS will work with agencies to develop the metadata requirements. The data will be included in a database to be developed by GSA, which shall be made publicly available through an open application program interface (API). Agencies shall continue to add new citizen science and crowdsourcing projects to the GSA database as the projects open up for public participation.

Agency Actions to Build Capacity for Citizen Science and Crowdsourcing

In the 2013 Open Government National Action Plan, the United States committed to develop an Open Innovation Toolkit for Federal agencies, in part to help agencies develop citizen science and crowdsourcing projects. The citizen science and crowdsourcing portion of the toolkit,

released in September 2015, was jointly developed by OSTP and the CCS. OSTP urges agencies to use the methods and examples in the Federal Crowdsourcing and Citizen Science Toolkit to design, carry out, and sustain effective citizen science and crowdsourcing projects. Agencies also should use the toolkit to share case studies, lessons learned, and best management practices.

In addition, OSTP encourages Federal agencies to build their capacity for citizen science and crowdsourcing by taking actions in each of the following areas:

- *Policy*. Develop clear agency-specific policies, procedures, and guidance to encourage and aid agency coordinators in developing and carrying out effective citizen science and crowdsourcing projects. The policies, procedures, and guidance should address common legal and process steps, including data collection and management, and should also discuss, as appropriate, issues connected to the Privacy Act, Paperwork Reduction Act, and protection of human subjects, as well as other ethical, legal, and social issues.
- *Resources and staffing*. In crafting programs and future budget requests, allow for the possibility of allocating funding and staff to citizen science and crowdsourcing projects (consistent with OMB Memorandum M-15-16, which encourages agencies to take innovative approaches such as citizen science into account in formulating their fiscal year 2017 budgets).
- *Technologies and scientific instrumentation*. Support the development of hardware, software, and mobile apps for citizen science projects that are affordable and easy to use and improve. Investments in low-cost technologies (such as a $1 microscope) can increase the variety and value of the contributions that citizen scientists can make.[8]
- *Diversity of projects.* Create mechanisms for providing small grants to individuals and communities that may not be affiliated with universities or traditional government contractors. Mechanisms such as DARPA's Fast Track Initiatives have provided small contracts to individuals, which has diversified the range of ideas for projects that receive funding. Similar approaches could be used to support citizen science and crowdsourcing projects.
- *Rigorous research and evaluation to improve current practice*. Devote resources to evaluating the effectiveness of citizen science and crowdsourcing projects in achieving agency objectives. Resources are also needed to develop methods for validating data and results from citizen science and crowdsourcing projects, and to evaluate the applicability of citizen science and crowdsourcing to the topics that are relevant to the missions of particular agencies. A broader, cross-project view is also needed such as, investing in the science of citizen science and crowdsourcing.

[8] Lee, M. 2015. Democratized scientific instrumentation: Leveraging the maker movement. Occasional Paper in Science and Technology Policy. Science and Technology Policy Institute.

Appendix

Benefits and Real-World Impacts of Citizen Science and Crowdsourcing

Citizen science and crowdsourcing are powerful approaches for engaging the public in the scientific process and in addressing societal needs. Federal agencies and nongovernmental organizations have mobilized millions of people to accomplish scientific work, from solving the structure of an AIDS-related enzyme (which may result in new medications) to mapping the 3-D structure of neurons in the brain. Volunteers have helped to discover a new class of galaxy and map the surface of Mars. Volunteers are collecting air quality and other environmental data to improve the health and well-being of their communities. They are also improving predictive models for coastal change and vulnerability to extreme storms. Researchers and entrepreneurs are contributing to biomedical research by partnering with the public to collect personal genomic data and patient or caregiver insights into disease. Volunteers have also enabled Federal agencies to address other societal needs beyond scientific research, including crowdsourcing time-critical information for emergency response and tagging millions of archival records. Local governments are combining crowdsourced traffic congestion maps and distributed-sensor data to shorten commuting times and make roads safer.

In addition, these approaches create opportunities for learning outside the classroom. Through citizen science and crowdsourcing projects, the American public are contributing their talents and creativity — as well as insights gained from a wide range of backgrounds and real-life experiences — to help agencies and researchers answer questions related to urgent real-world problems. Citizen science and crowdsourcing projects also enable individuals, groups, and local or virtual communities to follow their interests in new and unique ways to serve the public. Participants in these projects often gain new insights into public services and research, learning how to carry out projects at the local, regional, national, or global levels. When citizen science and crowdsourcing projects link American citizens with counterparts in other countries, such projects build understanding of shared international scientific challenges. These projects contribute to a more informed citizenry engaged in public service, a foundation of America's democratic system of government.

Most citizen science and crowdsourcing projects provide multiple benefits. For example, a 2015 synthesis of peer-reviewed literature describes the individual- and community-level impacts of volunteer environmental monitoring.[9] Specific outcomes reported in peer-reviewed journal articles include "improved communication between government and local stakeholders, increased knowledge and changed attitudes among participants, better adherence to natural resource regulations by community members, and empowerment of local stakeholders." Local stakeholders also became more engaged in ecosystem management and policy discussions, and the scientific literacy of participants grew. In addition, community-based monitoring or management led to improved relationships with the communities involved.

[9] Stepenuck, K.F., and L. Green. 2015. Individual- and community-level impacts of volunteer environmental monitoring. The Resilience Alliance.

Benefits of Citizen Science and Crowdsourcing Approaches

- *Enhance scientific research.* Citizen science and crowdsourcing help enhance and accelerate scientific research through group discovery and co-creation of knowledge. For instance, volunteers can collect data over large areas and long periods of time — and sometimes increase the frequency of observations — in ways that Federal agencies may not be able to do, given geographic and resource constraints. Volunteers also can provide unique perspectives and local expertise for interpreting data. In addition, the human eye and brain allow volunteers to categorize millions of objects (like galaxies) or find solutions to complex problems that computer algorithms may not be able to solve.
- *Address societal needs.* Citizen science and crowdsourcing projects not only augment and enhance the scientific process, but also address other societal needs while drawing on a vast reservoir of untapped resources — the skills, dedication, and ingenuity of the American people. Diverse participation by all parts of society helps bring in new ideas and insights and contributes to solutions. Citizen science and crowdsourcing can address a range of societal needs and Federal agency goals, ranging from enhancing the accuracy of prediction markets to tagging and transcribing national archive records.
- *Provide hands-on STEM learning and increase STEM literacy.* Whether as youth or as adults, participants in crowdsourcing and citizen science projects have the opportunity to acquire a life-long enthusiasm for science, along with valuable skills in science, technology, engineering, and mathematics (STEM). For students, working on "real-world" problems can make classroom learning experiences more exciting. For adults, working on crowdsourcing or citizen science projects can help them advance their knowledge and skills while contributing to the larger scientific enterprise. Volunteers gain hands-on experience with the scientific process, and they can apply what they learn in everyday life. Their experiences may also lead them to get involved in community decision-making, because active participation in citizen science and crowdsourcing projects helps members of the public and communities gain STEM literacy and learn about issues important to them.

Real-World Impacts of Citizen Science and Crowdsourcing

Below are summaries of real-world projects that illustrate each of the benefits described above.

Enhance Scientific Research

Advancing Disease Research. The NSF-NIH-USDA Ecology and Evolution of Infectious Diseases Program asked residents in the San Francisco Bay area to report outbreaks of sudden oak death, an invasive disease that kills oak trees. From the data, scientists developed accurate computer models for the disease's spread, showing that properly trained volunteers can collect data just as reliably as professionals. The data collected by participants was used to create the best predictive model on the spread of sudden oak death in California, which revealed novel findings about the spread of the disease. A 2015 study confirmed the results.[10]

[10] Meentemeyer, R.K., M.A Dorning, J.B. Vogler, D. Schmidt, and M. Garbelotto. 2015. Citizen science helps predict risk of emerging infectious disease. Frontiers in Ecology and the Environment 13: 189-194.

Advancing Phenological Research. In 2014 alone, volunteers participating in Nature's Notebook, a project of the USA National Phenology Network supported by USGS and NSF, recorded more than 1.5 million observations related to plants and animals. Scientists use the observations to analyze environmental change. Since Nature's Notebook was founded in 2009, it has amassed 5,500 active participants, 5.7 million records, and data on 31,000 unique organisms, including economically or culturally important species such as sugar maple, quaking aspen, monarch butterfly, northern leopard frog, and Sandhill crane. These crowdsourced data have contributed to 17 peer-reviewed scientific publications on topics as diverse as timing of ragweed pollen production, plant carbon uptake, onset of tree leafing in the eastern United States, and effects of climate variation on production of native seeds in California. A national-scale model based on these data demonstrated that 2012 had the earliest recorded onset of spring in recorded history, which was followed by a frost that cost millions of dollars in lost agricultural production. The North American Bird Phenology Program (USGS) has released over 400,000 records examining particular bird species and changes in their geographic locations over time to track the impact of a changing climate on migratory birds.

Identifying New Astronomical Objects of Interest. In 18 months, roughly 28,000 volunteers collectively made 1.4 million classifications of potential debris disks and protoplanetary disks surrounding young stars using Wide-field Infrared Survey Explorer (WISE) data through the NASA's Disk Detective project. Volunteers are needed because computer software cannot distinguish these disks from other infrared-bright sources, such as galaxies, interstellar dust clouds, and asteroids. Thousands of new planetary systems may exist in the WISE imagery, but the only way to know is to inspect each image by eye. These classifications have yielded 600 objects of interest, providing a crucial set of targets for future planet-hunting missions. The disk detective science team has used ground-based telescopes in Arizona, California, New Mexico, Hawaii, and Argentina to follow up on more than 200 volunteer-identified objects.

Verifying Weather Models. NOAA's mPING mobile app has collected more than 860,000 weather reports containing information on a variety of weather-related events, including rain, snow, ice, wind, tornadoes, floods, landslides, fog, dust storms, and more. On-the-ground weather information is collected from the public through smart phones or mobile devices with GPS-location capabilities. These reports from volunteers are used to improve weather computer models, forecast ground icing that could affect road maintenance and aviation operations, and predict the potential for in-flight icing. The data are also used to develop new radar and forecasting technologies and techniques.

Gathering Real-Time Natural Hazard Information. The Did You Feel It? program run by the U.S. Geological Survey (USGS) has enabled more than 3 million people globally to share what they experienced in earthquakes. The results contribute to rapid assessments of the extent and severity of damage and provide valuable data for scientific research, particularly in areas without dense sensor networks. Another USGS crowdsourcing project, Tweet Earthquake Dispatch (*TED*), searches for the word earthquake on Twitter and detects two to three earthquakes a day, on average. Especially in regions with few seismometers, *TED* reports often arrive before traditional seismic networks detect an earthquake, giving seismologists early warning.

TED sometimes detects earthquakes entirely missed by the USGS's automatic processing system, thereby increasing the number of felt events known to the agency (see 2014 study).[11]

Mapping the Human Brain. Based in the Seung Computational Neuroscience Lab at Princeton University, EyeWire (NIH) investigators are solving the mysteries of the brain with the help of the public. Over 150,000 people around the world have played what has been called a "3D neuroscience coloring book" — a puzzle game anyone can play without having any knowledge or experience in the field of neuroscience. EyeWire researchers aim to eventually map the human brain, but for now they are starting with the retina. Players are mapping the connections between retinal neurons, helping researchers understand how neurons process information.[12] Players have already helped researchers understand how a mammal can detect motion, which has remained a mystery — until now. EyeWire researchers hope their work can lead to advances in blindness therapies, the development of retinal prostheses, and other benefits.

Address Societal Needs

Improving Human Security through "Open Mapping". The Department of State, U.S. Agency for International Development (USAID), and Peace Corps support their humanitarian and development missions by supplying open geographic data created through crowdsourced mapping. These agencies mobilize volunteers around the world to contribute to OpenStreetMap, an open and editable map of the world. MapGive, a State Department initiative, engages volunteers online and holds team mapping events domestically and at foreign posts. USAID's Mapping for Resilience initiative recruits university students in the United States and abroad to collect data for USAID partners. Peace Corps taps into its network of current and returned Peace Corps volunteers to contribute to open mapping; Peace Corps is also recruiting and training middle and high school students throughout the United States. Over the past year, high-quality OpenStreetMap data have been used for "geo-coded" surveys to evaluate the effectiveness of indoor spraying for mosquitoes to prevent malaria in Botswana; disaster mitigation/planning, response, and recovery efforts in Nepal and the Philippines; hazard mapping and risk reduction in settlements surrounding volcanoes in Indonesia; and epidemiological monitoring and vaccination drives at refugee sites in South Sudan and Ethiopia.

Enhancing the Accuracy of Forecasts for Global Events. The goal of the Aggregative Contingent Estimation (ACE) Program (IARPA) is to dramatically enhance the accuracy, precision, and timeliness of forecasts for a broad range of global events. The program develops advanced techniques that gather, weight, and combine the judgments of people from many backgrounds, fields, and locations. Launched in 2010, ACE is based on the idea that combining the forecasts of an informed and diverse group often produces more accurate predictions of future events than a single expert can. The objective in this case was to improve forecasting by more than 50 percent over the state-of-the-art. By the program's end, the Good Judgment

[11] S.B. Liu. 2014. Crisis crowdsourcing framework: Designing strategic configurations of crowdsourcing for the emergency management domain. Computer Supported Cooperative Work 23: 389-443.

[12] Space-tie wiring specificity supports direction selectivity in the retina. Kim JS, Greene MJ, Zlateski A, Lee K, Richardson M, Turaga SC, Purcaro M, Balkam M, Robinson A, Behabadi BF, Campos M, Denk W, Seung HS, EyeWirers. Nature. 2014 May 15:509(7500):331-336.

Project had beaten the state-of-the-art by more than 70 percent. The ACE project shows that meaningful geopolitical forecasts can be produced quickly and accurately on topics ranging from violent international confrontations to how long international leaders will stay in power. By better measuring exact levels of uncertainty, the project can also increase the rigor of intelligence analysis more generally. Where traditional analysis can take days or weeks, ACE forecasts can be obtained in a matter of hours. And consumers of ACE forecasts can be confident in their accuracy, because the technologies have been validated in a real-world forecasting tournament.

Measuring Mobile Broadband Performance across America. More than 250,000 volunteers have joined the Federal Communications Commission's (FCC) Measuring Broadband America, offering broadband performance test data for Android and iOS as well as comments and feedback on improving Internet connectivity. The project does rigorous broadband performance testing for 13 of the largest wireline broadband providers, which serve well over 80 percent of the U.S. residential market, as well as wireless broadband providers. Data collected through the FCC Speed Test App are a rich source of information for mobile broadband consumers as well as industry and policymakers; volunteers can also use the app to test their own mobile broadband service on demand. Crowdsourcing was key to the FCC's ability to expand the scope of the program to include mobile broadband testing across the Nation. The mobile crowdsourcing program provides data that is unavailable from other sources at a cost that would be unattainable using traditional collection methods. The program's data support the FCC's mission to enable consumer choice and data-driven policy making on broadband and Internet services for consumers everywhere.

Tagging and Transcribing National Archival Records. National Archives and Records Administration's Citizen Archivist Dashboard coordinates crowdsourcing for tagging archival records and transcribing documents. More than 170,000 volunteers indexed 132 million names from the 1940 Census in five months, something that the National Archives could not have done alone. Similarly, the Smithsonian Transcription Center's 5,250 digital volunteers have completely transcribed and reviewed over 113,016 pages — a total that includes 859 projects shared by 13 Smithsonian archives, museums, and libraries. The "pages" include biodiversity specimens, from which data have been transcribed and used to create 27,004 new collection records for bumble bees and 23,488 new records for U.S. National Herbarium sheets.

Contributing Accurate Information about School Districts. In 2015, the Census Bureau introduced a new crowdsourcing application that allows agency geographers and participants from 35 states, as part of their State School District Review Program, to tag school district boundaries, report updates and changes, and resolve boundary discrepancies remotely and in real time. This simultaneous engagement between state-level geospatial data creators and the Census Bureau resulted in 10,000 boundary transactions occurring in its first iteration. Participating states marveled at the online tool's ease of use, the intuitive interface, and the streamlined program process. Benefits included reduced production times and elimination of mailing costs of program materials and maps. Minimal training was required for a wide range of user backgrounds.

Monitoring Pollution in Communities. The Environmental Protection Agency (EPA) Air Sensor Toolbox gives concerned citizens technical information on next-generation air monitoring

devices, including a description of new low-cost, real-time monitoring technologies and how to use them to meet a wide range of needs. The toolbox contains training materials, such as video and slide presentations, that are specifically designed for users of the new technologies. In the coming years, EPA will continue to update the toolbox based on its research on emerging technologies for air quality monitoring. By using the *Air Sensor Toolbox*, citizen scientists can help fill knowledge gaps about the quality of their local air, leading to regulatory action, technology improvements, and less air pollution.

Provide Hands-on STEM Learning and Increase STEM Literacy

Leveraging Citizen Science for Classroom and Out-of-School Learning. NSF's Monarch Larva Monitoring Project (MLMP) engages volunteers in monarch butterfly research, collecting data that otherwise would be very difficult to get. MLMP conducts intensive summer workshops for teachers and youth leaders, who work with youth in and outside of schools as well as in urban, suburban, and rural communities. They help youth not only collect data for MLMP but also examine the data themselves and ask questions of personal interest. An analysis of all 503 published papers on monarch butterflies since 1940 showed that 17 percent included citizen science data. The MLMP project has resulted in 18 scientific papers and two education research papers to date.

Increasing Scientific Literacy and Local Capacity. In Puerto Rico, Para La Naturaleza, supported by NSF, organizes citizen science projects related to the local environment, including monitoring bats, frogs, and coastal sands. The goal is to generate scientific knowledge about the region and build local capacity. Through self-report surveys, participants have indicated that citizen science activities increase their knowledge of local plants, animals, and habitats and their ability to generate scientific questions about the environment. Some participants started out as occasional volunteers and now play leadership roles in the research projects, including leading and training other volunteers.

Increasing Scientific Literacy through Citizen Science Astronomy. NSF's Citizen Sky project provides opportunities for participants, whether new to astronomy or seasoned amateur astronomers, to engage in various aspects of astronomical research. Participants collect and analyze data on a scale that scientists alone could never match; sometimes the participants join in publishing project findings. A study[13] showed that participants' attitudes toward science improved over 6 months of participation, with increases in scientific literacy strongly related to participation in the social components of the Citizen Sky project. Surprisingly, participants' confidence in their own scientific knowledge and ability decreased over the 6-month study period. Interviews with participants suggested that their declining self-confidence resulted from having come to a deeper understanding of what they have yet to learn.

Monitoring Beaches for Seabirds. NSF's Coastal Observation and Seabird Survey Team (COASST) has about 850 volunteers who monitor seabird carcasses at over 350 beach sites in California, Oregon, Washington, and Alaska. Resulting data advance the science of coastal

[13] Price, C. A. and Lee, H.-S. (2013), Changes in participants' scientific attitudes and epistemological beliefs during an astronomical citizen science project. J. Res. Sci. Teach.. doi: 10.1002/tea.21090

ecology and contribute to natural resources management. COASST has documented the world's single largest die-off of seabirds from a harmful algal bloom and contributed to analyses of the potential impacts of development on coastal ecosystems in the Pacific Northwest. COASST volunteers learn bird identification skills and the seasonal patterns of bird activity, and they use the data they collect in ways relevant to their communities, for example to address the issue of fishery bycatch in Boundary Bay, WA. This project shows how citizen science strengthens communities and influences decision making.

Monitoring Precipitation. The Community Collaborative Rain, Hail and Snow Network (CoCoRaHS), supported by NOAA and NSF, offers hands-on STEM education while contributing to scientific research by collecting data from an unprecedented number of sites. Each time a rain, hail, or snow storm crosses their area, volunteers measure the precipitation using low-cost tools; then they report the measurements on the CoCoRaHS website. CoCoRaHS boosts education and climate literacy through daily messages, newsletters, webinars, educational videos, and outreach events. Started in 1997, the network now has over 20,000 volunteers in all 50 States, the District of Columbia, Puerto Rico, the U.S. Virgin Islands, and Canada. The National Weather Service uses CoCoRaHS data — combined with information from other sources — to create daily precipitation maps and decide whether to issue severe weather warnings. The project encourages student participation, and a recent report found that participating students made gains in their science skills and were more likely to aspire to a career in STEM. As one teacher put it, "That's all my kids talked about … They were so excited to think that … what we record every day matters." Since 2012, over 20 peer-reviewed publications have used CoCoRaHS data.

Validating Satellite Data around the World. Since 1995, the Global Learning and Observations to Benefit the Environment Program (GLOBE), supported by NASA and NSF has received more than 2.3 million cloud data reports from nearly 15,000 locations around the world. In partnership with GLOBE, Students' Cloud Observations Online (S'COOL) has received more than 135,000 observations from around the world since 1997, of which more than half could be matched to satellite overpasses. The GLOBE/S'COOL partnership is a vast source of information about clouds, engaging citizens around the world in authentic science. Students work together with scientists on specific questions; collect and enter data into a global database; and analyze the data, presenting their research at GLOBE meetings. Cloud observations from the ground complement the data provided by multiple satellites; GLOBE students also measure surface soil moisture to help calibrate and validate remote observations. GLOBE precipitation data support satellite missions to measure precipitation, and GLOBE students also report plant cover to help NASA create "land cover" maps using Landsat natural-color and infrared imagery. All of these activities have increased public awareness of satellite missions and built a sense of public partnership with the U.S. Government. Many GLOBE students go on to STEM careers, while others work with the GLOBE community as alumni.