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Empowering Participation in Science: A Citizen Science Landscape

An overview of projects that engage the public in environmental and ecological research.

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Introduction

On April 5th, 2024, an M 4.8 earthquake occurred in Tewksbury, NJ. While earthquakes of this magnitude are not impossible in this region—they have actually occurred multiple times before—the severity shook the lives of those in the Northeast and Mid Atlantic, literally and figuratively.

Natural disasters have a history of being recorded to help predict when and where they will occur with the intention to mitigate their damages. For earthquakes specifically, scientists use "hazard mapping" to try to determine the probability an earthquake will occur within a set timespan for specific regions. As technologies with more readily available sensors emerged, researchers started to engage volunteers to utilize their sensor-equipped smartphones to help record natural disaster patterns and improve techniques like hazard mapping, including projects like MyShake, Is Ash Falling?, and NOAA SKYWARN. Projects that engage the public in disaster risk reduction are just a small portion of a wide breadth of initiatives to engage the public in science. There are many other types of projects with different goals, tasks, and types of participation.

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In this report, we provide an overview of projects that engage the public in environmental and ecological research, identifying the benefits, some challenges, and types of projects. We offer case studies of repositories that fall at the intersection of environmental science and practice.

Defining Citizen Science

There is no single accepted definition of citizen science (see National Academies of Sciences, Engineering, and Medicine, 2018). For example, the Federal Crowdsourcing and Citizen Science Act of 2016 defines "citizen science" as a form of open collaboration in which individuals or organizations participate in the scientific process in various ways, including enabling the formulation of research questions; creating and refining project design; conducting scientific experiments; collecting and analyzing data; interpreting the results of data; developing technologies and applications; making discoveries; and solving problems. For the purposes of this report, we define citizen science projects as those that involve members of the public in the process of research. This closely aligns with existing and commonly cited definitions of "Public Participation in Scientific Research (PPSR)" (c.f. Bonney et al., 2009; Shirk et al., 2012), as well as Fraisl et al. (2020)'s decision to define citizen science using the characteristics of "public participation," "voluntary contributions," and "knowledge production" (p. 1736). Finally, we also include any projects that self-identify as citizen science, or related terms such as community science (see Cooper et al., 2021; Lin Hunter et al., 2023b for further discussion).

Recently, some organizations including federal agencies, have shifted to alternative language to describe this and related approaches in order to communicate the inclusive and welcoming nature of these approaches to science. The Smithsonian Environmental Research Center, for example, now uses "participatory science" to describe a range of efforts to engage volunteers in the scientific process.

In this report, we continue to refer to this work as "citizen science," due to its use globally and recognizing its use in the Crowdsourcing and Citizen Science Act of 2016, acknowledging that the title of "citizen science" brings its own unique implications, challenges, and barriers to access (Cooper et al. 2021). In addition, we focus primarily on those projects that engage the public in research defined and directed by professional scientists in the context of their institutions, defined below as "contributory" projects.

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Goals

Citizen science projects advance a diverse range of goals, including:

- Producing large-scale, quality data and/or data analysis to accelerate research agendas (e.g. Cooper, 2016);
- Supporting learning and interest in science (e.g. Forrester et al., 2017; Smith et al., 2021);
- Raising awareness about a particular issue (e.g. Stepenuck and Green, 2015);
- Increasing civic engagement (e.g. Condon and Wichowsky, 2018; Stepenuck and Green, 2015); and
- Democratizing scientific research (e.g. Walker et al., 2020).

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Challenges

Public participation in the scientific process offers important benefits, but also presents unique challenges.

Data Quality and Interoperability

Citizen science projects address and communicate the techniques used to ensure the quality (e.g. validity, reliability, and accuracy) of data generated by public participants. Techniques to improve data quality include training, consistent and clear data collection protocols, expert and/or peer verification, and large sample sizes (Balázs et al., 2021; Cooper, 2016; Kosmala et al., 2016). Quality assurance procedures also improve data interoperability, allowing data to be used across different systems and projects.

Participant Diversity

Another major challenge facing many citizen science projects is a lack of participant diversity. Participants in citizen science, especially contributory projects, tend to be disproportionately white, highly educated, and affluent (Allf et al., 2022; Mahmoudi et al., 2022; Pateman, 2021; Waugh et al., 2023). This lack of diversity creates the potential for bias and data gaps; it may also compound existing inequalities (e.g. in the underrepresentation of certain communities in STEM) and hinder innovation (e.g. from integrating forms of knowledge apart from conventional scientific research) (Blake et al., 2020; Cooper, 2016; Pateman and West, 2023). To address this and provide transparency, some projects collect and report information on participant demographics (c.f. Waugh et al., 2023). Projects may also foster diversity by lowering barriers to participation for diverse communities (Blake et al., 2020), adapting projects to local values and issues (Paleco et al., 2021), and partnering with facilitator organizations, such as historically Black colleges and universities (Lin Hunter et al., 2023a).

Recruitment and Retention

Citizen science projects may experience challenges with participant recruitment and retention. For example, the Community Collaborative Rain, Hail & Snow Network (CoCoRaHS) sees about half of initial participants return for a second year (Cooper, 2016; Reges et al., 2016). Existing research often points to the importance of better understanding why people participate in citizen science, tailoring marketing to appeal to participants' unique motivations, clearly communicating with participants, and investing in the development of easy-to-use tools (Fritz et al., 2022; Hart et al., 2022). Robinson et al. (2018) also suggest that retention and long-term success may be improved by ensuring professional and citizen scientists benefit from participation, recognizing the contributions of public participants through badges, certificates, co-authorship, or other mechanisms, and involving public participants in multiple stages of the scientific process.

Types of Citizen Science Projects

In this section, we describe commonly cited typologies that attempt to classify citizen science. The characteristics used to differentiate citizen science projects include the degree of public participant involvement, the goals of the study, and the types of tasks that public participants conduct.

Public Participant Involvement

The most commonly cited typologies differentiate citizen science projects by the degree of participant control and/or engagement. These typologies originate from an Inquiry Group sponsored by the National Science Foundation's (NSF) Center for the Advancement of Informal Science Education (CAISE), which convened practitioners and researchers on the topic of public participation in scientific research (PPSR). Bonney et al. (2009) divide PPSR projects into three categories (contributory, collaborative, co-created), based on who designed the project and what stages of the scientific process public participants were actively involved in. Shirk et al. (2012) expand this framework to include five categories (Table 1). Similarly, Haklay (2012) offers four degrees of participant engagement (crowdsourcing, distributed intelligence, participatory science, and extreme citizen science), focusing on the relationships between scientists and public participants. It is important to acknowledge that most of these typologies are inherently hierarchical, reflecting a belief that citizen science projects with more participant control are preferable to those with little to no participant control.

Table 1. Typology by Shirk et al. (2012)

Category	Description	Example(s)
Contractual	"communities ask professional researchers to conduct a specific scientific investigation and report on the results"	
Contributory	"generally designed by scientists and for which members of the public primarily contribute data"	NestWatch Community Collaborative Rain, Hail, & Snow Network
Collaborative	"generally designed by scientists and for which members of the public contribute data but also help to refine project design, analyze data, and/or disseminate findings"	Galaxy Zoo
Co-Created	"designed by scientists and members of the public working together and for which at least some of the public participants are actively involved in most or all aspects of the research process"	ReClam the Bay Gardenroots
Collegial	"non-credentialed individuals conduct research independently with varying degrees of expected recognition by institutionalized science and/or professionals"	

Project Goals

In contrast, Wiggins and Crowston (2011) develop a typology based on a project's goals. Most of the categories in this typology are differentiated by whether they are primarily concerned with civic agendas (action), stewardship and natural resource management (conservation), scientific research and formal knowledge production (investigation), or education and outreach (education), with the exception of the Virtual category, which shares similar goals to other categories but is differentiated by its exclusive use of ICT (Table 2).

Table 2. Typology by Wiggins and Crowston (2011)

Category	Description	Example(s)
Action	"encourage participant intervention in local concerns, using scientific research as a tool to support civic agendas"	North Carolina Primary Source Transcription
Conservation	"support stewardship and natural resource management goals"	Penguin Watch
Investigation	"focused on scientific research goals requiring data collection from the physical environment"	Community Collaborative Rain, Hail, & Snow Network
Virtual	"all project activities are ICT-mediated with no physical elements"	Galaxy Zoo
Education	"make education and outreach primary goals"	Globe at Night ReClam the Bay

Types of Tasks

Alternative typologies differentiate projects according to the types of tasks that members of the public conduct. Chung and Scassa (2015) define four categories of public participant contributions: classification or transcription of data; data gathering; participation as a research subject; and the solving of problems, sharing of ideas, or manipulation of data. Strasser et al. (2019) identify five "epistemic practices" that differentiate projects: sensing, computing, analyzing, self-reporting, and making.

Other

Other differentiating factors of citizen science projects include:

- **Location**: Projects might be localized, limited to certain states, regions, or climates, national, or worldwide.
- **Time**: Projects might occur in a limited time frame (a single event or season) or year-round.
- **Funding**: Many citizen science projects receive funding from government sponsors, such as the NSF. Most

projects that we discovered received backing from academia.

These factors will be explored further in the case studies.

A comprehensive taxonomy of citizen science projects might combine these axes of differentiation into a multidimensional framework (see Franzoni et al., 2022).

Representations of Different Project Types

To better explore the use of citizen science in the environmental and ecological sciences and present case studies to represent different types of citizen science, we identified potential cases through online search engines and repositories (notably Google, SciStarter, and CitizenScience.gov), the expertise of Wilson Center researchers, and articles and books about citizen science (e.g. the taxonomies referred to above). These projects are based in the United States, although some operate globally.

Community Collaborative Rain, Hail & Snow Network (CoCoRaHS)

The Community Collaborative Rain, Hail & Snow Network (CoCoRaHS) is a nonprofit network of over 26,000 active volunteers who measure local precipitation. Participants are located across the US, as well as in Canada and the Bahamas, and collectively make up the largest provider of daily precipitation observations in the US.

CoCoRaHS has several processes in place to ensure data quality, such as volunteer training (free in-person and online training are available) and standardized requirements for equipment and collection procedures (observers must purchase an approved 4-inch rain gauge and are instructed to take measurements at the same time every day). The large volume of observations, as well as observers' intrinsic motivation to collect high-quality data, also increase confidence in CoCoRaHS' data quality.

Daily precipitation data from CoCoRaHS are immediately made public, for free, which enables a wide range of applications. The National Oceanic and Atmospheric Administration (NOAA) uses CoCoRaHS data for weather forecasting, warnings, and verification. CoCoRaHS data are also used by the US Department of Agriculture to drought-related conditions and impacts, researchers to track and control mosquitoes, and insurance companies to verify damage claims, among other uses.

CoCoRaHS originated at the Colorado Climate Center at Colorado State University, and its major sponsors are NOAA and the NSF.

Typology Tags: Contributory, Investigation, Regional, Year-Round

ReClam the Bay

ReClam the Bay (RCTB) is a nonprofit organization that engages public participants in growing shellfish. Although volunteers help to restore shellfish population in the Barnegat Bay Watershed, New Jersey, RCTB is primarily focused on educating the public on the importance of shellfish and the environment. As such, the organization hosts educational events at museums, schools, farmers markets, and other local sites. A different project, the Clam Trail, brings members of the public on a "scavenger hunt," where participants can earn prizes by finding giant clam sculptures at different points of interest throughout Barnegat Bay.

Participants are "deeply engaged in all aspects of the project" (Bonney et al., 2009, p. 39). Volunteers attend Coastal Stewardship Classes to become Certified Shellfish Gardeners, help grow and plant shellfish, and create and conduct educational sessions, among other tasks. They have also collaborated with scientists to develop research questions, create hypotheses, and interpret data (Bonney et al., 2009).

Typology Tags: Co-Created, Education, Localized, Year-Round

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Great Backyard Bird Count

The Great Backyard Bird Count (GBBC) is a four-day event, held annually in February, that invites the public to observe and count as many birds as they can find. GBBC is a partnership between the Cornell Lab of Ornithology, National Audubon Society, and Birds Canada, which each run other well-known citizen science projects (e.g. Celebrate Urban Birds, the Christmas Bird Count, and Project FeederWatch). In 2023, GBBC had over 500,000 participants from 202 participating countries.

The project is explicitly marketed towards bird watchers of all ages, around the world. Barriers to participation are extremely low: Participants can create an account on the GBBC website or one of two free mobile apps (Merlin Bird ID or eBird), do not need to undergo training, and are asked to count for as little as 15 minutes.

Annual counts are available online. The GBBC website provides limited information on how the data are used, with the FAQ stating that the information "helps scientists learn how birds are affected by environmental changes."

Public participants generally appear to be uninvolved in stages other than data collection.

Typology Tags: Contributory, Education/Conservation, Worldwide, Limited Time Frame

Globe at Night

In Globe at Night, public participants measure and submit night sky brightness in their local area. The goal of the project is "to raise public awareness of the impact of light pollution."

In 2022, the campaign received about 20,000 observations from 79 countries. Participants submit observations using a form on the Globe at Night website (accessible via mobile or desktop). The measurements are freely available on the project's website, under a Creative Commons Attribution 4.0 International License.

Globe at Night is a program of the NSF's NOIRLab, which is operated by the Association of Universities for Research in Astronomy, Inc. (AURA).

Typology Tags: Contributory, Education, Worldwide, Year-Round

Gardenroots

Gardenroots is a citizen science partnership between University of Arizona scientists and Arizona residents. The project first began in Dewey-Humboldt, Arizona, after residents expressed concerns about a nearby Superfund site's impact on the vegetables grown from their home gardens. It is now active in three Arizona counties, with additional projects in Troy, NY, USA and Arica, Chile.

Participation in the project generally follows four steps:

1. Training and community gathering: Residents are trained to collect water, soil, plant, and/or dust samples.
2. Submission: Residents drop samples off at the nearest University of Arizona Cooperative Extension office.
3. Testing: University of Arizona researchers test samples for potential contaminants.
4. Results: Community members and researchers gather to discuss results.

Community members are involved throughout this research process. Not only did participants develop the project's research question and collect samples, they were invited on a tour of the University of Arizona laboratories where testing is conducted and became involved in civic action to encourage government agencies to take action. All participants also receive individualized test results of their home gardens, to help gardeners make informed decisions about their gardening practices.

Typology Tags: Co-Created, Investigation, Localized, Year-Round

City Nature Challenge

The City Nature Challenge (CNC) is an annual competition to encourage people to find and document nature in cities. Originally a competition between Los Angeles and San Francisco, CNC is run by the community science teams at the Natural History Museum of Los Angeles County and the California Academy of Sciences.

The competition takes place over about a week and encourages people of all ages and backgrounds to participate. In 2023, 66,394 participants from around the world submitted over 1.8 million observations.

In most cities, participants record observations of wild plants and animals using the iNaturalist app. Although all submissions count towards the competition, iNaturalist has a built-in data quality assessment procedure to identify observations for research, although the validity of this procedure has been called into question (see McMullin and Allen, 2022).

Typology Tags: Contributory, Education, Worldwide, Limited Time Frame

Iguanas from Above

In Iguanas from Above, public participants count iguanas in drone images to help scientists monitor marine iguanas in the Galápagos Islands. The project is hosted on Zooniverse, a popular citizen science web portal. As of February 2024, over 12,000 volunteers have contributed to the project.

Participants' counts are compared to ground-based surveys to ensure data quality. Researchers hope to use the data to create estimates of the size and location of marine iguanas, which will then be used to develop a conservation plan to protect the vulnerable subspecies.

Typology Tags: Contributory, Virtual, Worldwide (in terms of participation, with data from a localized area), Year-Round

Abuzz

Abuzz is a project out of Stanford University that aims to diminish the risk of malaria and Zika through crowd-sourced acoustic surveillance of mosquitos. Submissions of audio, recorded through participants' smartphones, can be posted through their webpage.

Data is crowdsourced via participants' audio submissions. Sponsored by the Coulter Foundation and National Institutes of Health, Abuzz works on a global-scale, accepting submissions from many regions.

Typology Tags: Contributory, Investigation, Worldwide, Year-Round

The Lost Ladybug Project

The Lost Ladybug Project aims to track the changing composition of the North American ladybug population. Participants submit photographs of ladybugs via the project's website. As of February 28th, 2024, over 39 thousand submissions have been contributed to the project.

The Lost Ladybug Project began in 2000 in a collaboration between Cornell University researchers and 4-H Cooperative Extension Master Gardeners. Other partners include the NSF and DiscoveryLife.org. Education is a key component of the project's mission, and the Lost Ladybug Project encourages participation by children.

Typology Tags: Contributory, Conservation, Regional, Year-Round

MyShake

MyShake's goal is to build a "worldwide earthquake early warning network." The project uses smartphone sensors to detect if certain motions fit those of an earthquake. Participants can also submit and view damage reports. The app has 1.6 million downloads from users spanning more than 80 countries.

MyShake is a project of the Berkeley Seismology Lab, out of the University of California, Berkeley. Early warning alerts based on the project's data are currently available in California, Oregon, and Washington, thanks to a partnership with USGS and the California Governor's Office of Emergency Services.

Typology Tags: Contributory, Investigation, Worldwide, Year-Round

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Nurdle Patrol

In Nurdle Patrol, public participants find and map nurdles, plastic pellets that can negatively impact marine life and the environment. The project is run by the Mission-Aransas National Estuarine Research Reserve at the University of Texas Marine Science Institute. As of November 2023, five years after the project was established, over 9,000 participants have submitted over 20,000 surveys (Tunnell, 2023).

To reduce barriers to participation, the project distributes free interactive kits for educators and organizations. The project has published its sampling methodology (Tunnell et al., 2020) and, in an effort to improve data quality, offers free training videos and conducts daily reviews of its database.

Typology Tags: Contributory, Conservation, National, Year-Round

Conclusion

For those that are interested in citizen science, there are many projects and initiatives seeking volunteers. While every citizen science initiative has its own unique goals and topics, creating frameworks, or typologies, based on their similarities provides aspiring citizen scientists with avenues to explore the types of projects that most interest them.

Typologies of citizen science frameworks do not have to end here. With the existing repertoire of typologies as a catalyst, new ways to think about citizen science projects can coalesce. For example, a typology based on reach and impact would be helpful to explore. Rather than identifying the intended audience or intended amount of contributors, a direction citizen science researchers can explore is who will be benefiting from the information gathered and on what scale is this information disseminated.

We hope that with the examples of citizen science projects provided, readers can use this as inspiration for further exploration. Citizen science provides not only a good entry point into contributing to environmental sciences but is scalable for those with more interest to dive in further.

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