Civic Technology and Community Science: A new model for public participation in environmental decisions

Tecnologia cívica e ciência comunitária: um novo modelo de participação pública em decisões ambientais

Shannon Dosemagen *

Gretchen Gehrke **

RESUMO

Desde seu inicio, o Public Lab tem sido uma comunidade aberta que desenvolve e usa tecnologias cívicas para enfrentar problemas definidos pela comunidade e questões ambientais também identificadas pela comunidade. Organizada como uma comunidade global sem fins lucrativos com escritórios em vários estados americanos, Public Lab introduz um modelo de ciência comunitária que incorpora práticas de fonte aberta incluindo a colaboração transparente e desenho iterativo, junto com a governança deliberativa democrática e o empoderamento dos participantes pelo fazer (*making*) crítico apoiado por uma rede de ciência aberta. A ciência comunitária capacita os membros de uma comunidade a coletar, interpretar e aplicar seus próprios dados para efetuar a mudança local para efetuar a mudança local ou participar de movimentos mais amplos de pesquisa ambiental e tomada de decisões.

Os autores conceituam uma abordagem em camadas do desenvolvimento de projetos, sendo as camadas delineadas pelo escopo dos objetivos da comunidade e do papel exercido pela ciência comunitária em atingi-los.

A Camada 1 inclui a ciência performativa

ABSTRACT

From its inception, Public Lab has been an open community developing and utilizing civic technologies in pursuit of community-defined questions and to address community-identified environmental concerns. Organized as a global community with nonprofit offices in several U.S. states, Public Lab introduces a model of community science, which incorporates open source practices including transparent collaboration and iterative design, along with deliberative democratic governance, and practitioner empowerment through critical making supported by an open science network. Community science can enable community members to collect, interpret, and apply their own data to effect local change or participate in broader environmental research and decision-making.

The authors conceptualize a tiered approach to project development, with tiers delineated by the scope of community objectives and the role of community science in achieving those objectives. Tier 1 includes performative science used to engage the public but without direct application toward community goals. Tier 2 involves community science created and

* MS in Anthropology and Nonprofit Management. Public Laboratory for Open Technology and Science. Address: PO Box 426113, Cambridge, MA 02142. Phone: +1-504-239-4642. E-mail: shannon@publiclab.org

** PhD in Geochemistry. Public Laboratory for Open Technology and Science. Address: PO Box 426113, Cambridge, MA 02142. Phone: +1-504-239-4642. E-mail: gretchen@publiclab.org

usada para envolver o público, mas sem uma aplicação direta para os objetivos da comunidade. A Camada 2 envolve a ciência comunitária criada e conduzida pelos membros visando objetivos relevantes para a comunidade. A Camada 3 incorpora parceiros institucionais , partindo de dados da comunidade em processo colaborativo visando atingir objetivos com implicações mais abrangentes. Exemplos apresentados de projetos de cada Camada demonstram a versatilidade da ciência comunitária assim como seu potencial de facilitar a participação pública na tomada de decisões ambientais em múltiplos níveis.

Palavras-chave: Ciência Comunitária; Práticas de Fonte Aberta; Rede de Ciência Aberta; Pesquisa Ambiental.

conducted by members for community-relevant outcomes. Tier 3 incorporates institutional partners, building upon community data through collaborative process to achieve community goals with broader implications. Examples of Public Lab projects from each tier demonstrate the versatility of community science, and the potential opportunity for community science to facilitate public participation in environmental decision-making on multiple levels.

Keywords: Community Science; Open Source Practices; Open Science Network; Environmental Research.

INTRODUCTION

The Public Laboratory for Open Technology and Science (Public Lab) is an open community and nonprofit organization that develops and applies low-cost, open-source monitoring tools to address environmental issues. Although organized globally, nonprofit staff are located in five U.S. cities-- New Orleans (LA), Durham (NC), New York City (NY), Somerville (MA), and Portland (OR). The community organizes online at publiclab.org. The Public Lab nonprofit is primarily funded through philanthropic foundation grants and earned revenue from DIY kit sales, allowing the nonprofit to create online infrastructure for communities to utilize, seed and steer tool development, and provide community stipends for supporting portions of community projects. Public Lab partners are not required to have a financial relationship with the nonprofit; the community is open to all.

Public Lab was formed as a community-led democratic response to the lack of transparency and public dissemination of information during the BP oil spill in 2010. As the Federal Aviation Administration restricted flight access, and British Petroleum and the U.S. Coast Guard restricted media access by boat, there was effectively a media blackout, leaving Gulf Coast residents without access to crucial information about impacts on their local environment (McClintock, 2012; Peters, 2010; Philips, 2010). In response, local community organizers, concerned residents, environmental advocates, technologists and designers from around the country worked together to develop and deploy low-cost tools to enable community members to gather their own data. Using balloons and kites rigged with digital cameras, Gulf Coast residents were able to take high-resolution aerial photographs, providing oil spill documentation during a time when the media were not able to, and the industry would not. The aerial maps were posted freely online. Media learned of the community aerial mapping project through word of mouth, and outlets including CNN and the New York Times featured the work, increasing public awareness and access to vital information (CNN, 2010; New York Times, 2010). From its inception, Public Lab's primary objectives have been to increase awareness and accountability of environmental issues through community science.

Grassroots aerial mapping efforts in the Gulf Coast were successful because of the democratic, transparent, multidisciplinary, and multimodal structure of collaboration, which continue to be pillars of the Public Lab model today. Responding to the oil spill, people with diverse experience in cartography, aeronautics, coding, community mobilization, advocacy, and local geography collaborated in a non-hierarchical fashion, with each contributing essential skills and knowledge.

Today, Public Lab continues to practice and promote horizontal multidisciplinary collaboration, challenging traditional roles of experts and laypeople. Additionally, Public Lab utilizes communication technologies to provide opportunity for participation in different capacities. Using a hybrid online-offline model, Public Lab supports work that is simultaneously globally distributed and locally focused, effectively bolstering local efforts through online communications, software and hardware developments, and resource sharing. The Public Lab model was constructed to be accessible and modular, to be borrowed from by other groups who are discovering ways to leverage traditional models of community organizing with new media tools and technologies.

When developing community science projects, articulating local community objectives is one of the first steps. To increase the likelihood of achieving beneficial outcomes, it behooves communities to then evaluate their outcomes sought, currently available resources, and necessary resources for achieving intended outcomes. Public Lab conceptualizes project development in different tiers depending on the role of community science and the internal and external partnerships necessary for success. Public participation is intrinsic to community science and Public Lab actively advocates for impactful public participation in environmental decision-making on all levels, through partnerships and through increasing community regulatory and scientific data literacy. This manuscript describes innovative facets of Public Lab's model and introduces the tiered approach of Public Lab project definition and development, including autonomous community projects and progressive community-institutional partner projects.

FRAMING A PARTICIPATORY ENVIRONMENTAL SCIENCE COMMUNICATION MODEL

Over the last decade there has been increasing interest in the use of low-cost data collection and communication technology to support the efforts of community groups becoming stakeholders in environmental decision making processes. Public Lab builds on the theory of civic science (Fortun and Fortun, 2005), to create an open, collaborative space in which information sharing and collective knowledge production lie at the center of the community. In this section we discuss the framework for how the Public Lab community interacts, communicates, effectively uses open and low-cost technology to enhance participation, and contributes to community directed advocacy. We discuss the unique components of Public Lab's model that combine civic technology, community science and environmental application, and demonstrate their ability to tangibly enhance participation. We borrow heavily from case studies within Public Lab as the community has been a leader in the field of civic technology, crowdsourcing and community science, and stimulating questions about public participation in environmental science research (Shirk, et. al. 2012) and decision making.

Citizen, Civic and Community Science

Citizen science is the engagement of the public to participate in scientific research, typically in a model that crowdsources data collection for a study led by professional researchers, where data ownership and application reside with the professional researcher, ultimately for educational and scientific advances (Bonney, et. al., 2009). Crowdsourcing (Howe, 2006) in this instance is a form of information gathering where "the crowd," individuals collectively inserting information around specific topics, supports researchers through the contribution of information or independently collected data. Although Public Lab supports the work of citizen science projects and institutions, the Public Lab model challenges traditional roles of expertise through open collaboration and multi-directional learning, and focusing on outcomes relevant to community members. Public Lab members become researchers and practitioners rather than project participants or users. Additionally, Public Lab promotes "full data lifecycles" (Warren and Dosemagen, 2011) in which data and information collected by all researchers are owned, interpretable and actionable for their purposes.

Another model of participatory science is civic science, defined as "[a science] that questions the state of things, rather than a science that simply serves the state," (Fortun and Fortun, 2005, p. 50). Within the realm of civic science, open technology may be leveraged to redefine relationships between science and the public, a practice that has been called civic technoscience (Wylie, et. al., 2014).

Public Lab builds on the theory of civic science, with the foundation of civic technology, to create a model of community science. We define community science as collaboratively-led scientific investigation and exploration to address community-defined questions, allowing for engagement in the entirety of the scientific process. Unique in comparison to citizen science, community science may or may not include partnerships with professional scientists, emphasizes the community's ownership of research and access to resulting data, and orients towards community goals and working together in scalable networks to encourage collaborative learning and civic engagement.

Open Spaces

Public Lab relies on a distributed network of practitioners-- technologists, activists, scientists, and professionals from the fields of law, policy and health-- to create the meaningful integration of technology into community activism. The larger Public Lab community builds on processes of cooperation and collaboration (Eaves, 2014; Ashkenas, 2015) in which communication is an integral part of Public Lab's decision-making process. The licensing used in Public Lab (CERN OHL 1.1; GPLv3; CC-BY-SA) supports and requires open, collaborative information sharing about the hardware and software design of environmental monitoring tools, project contextualization, and in many cases open access to data for others to use in their own work with proper attribution. Open licensing protects contributors from others creating unmodifiable forks, patents or using proprietary licensing.

Open access and sharing through a central communication platform, where people and projects are encouraged to share early and often, is fundamental to open source communities (Kelty, 2008; Coleman, 2013) whose principles support the rapid iteration and testing of ideas and prototypes, documentation of successes and failures, and transparency as projects are created, maintained and completed. In the Public Lab community, practitioners, including community organizers and advocates, scientists, educators, government and others are encouraged to share across projects, to integrate research and goal setting between advocates, designers, and developers. Integration facilitates effective application-oriented civic technology development and implementation in campaigns where data acquisition plays an important role in community advocacy.

Critical making and a DIY ethos

Through the open research process described above, the Public Lab community has created tools for aerial imaging, a plant-based air remediation kit, a spectrometer and more. The model of "making" that Public Lab uses relies on participation of community practitioners in the creation of tools as an important step in understanding how each tool can be used in data collection, and how resultant data can be applied. The "critical making" (Ratto, 2011) approach that Public Lab takes evolved from the "Do-It-Yourself" (DIY) revolution in home crafting and art, combined with the ideology of the "maker movement", incorporating an ethos of creating something independently rather than relying on a pre-constructed object. The DIY process removes the "black box" (Latour, 1987; Resnick 2000) inherent to proprietary material objects, and is central to understanding the underlying mechanisms that make an object function. Self and community education is an important aspect of critical making (DiSalvo, 2009). The DIY tools and techniques designed, developed, or applied in the Public Lab community often serve as both hands-on learning opportunities to understand underlying scientific assumptions or phenomena, while also collecting environmental data. Moreover, the critical making process helps develop technical and scientific literacy among practitioners, and encourages purposeful technology. For example, the Public Lab community is currently iterating development of a reliable low-cost DIY conductivity meter, after different members of the community identified the potential for and then demonstrated that the original voltage used caused electrolysis of water samples. The community's collective capacity is growing, as people who usually apply technologies and people who usually build technologies collaborate in critical making. The DIY tools are, in general, less precise and sensitive than traditional equipment used in laboratories, but can be an important step in unveiling the need for further data, or for further elucidating scientific or policy assumptions. Public Lab's process creates cost-accessible DIY environmental technology, with concomitant advances in technological or scientific literacy to better engage in environmental discussions and decision-making.

Expanding understandings of expertise in public participation

Open spaces, collaborative ideation, and DIY tool development suggest that useful expertise is not confined to institutional definitions of "the expert" (Epstein, 1995) . Arguments from researchers such as Harry Collins (2014) suggest that there is a hierarchy to types of expertise, culminating in the pedigreed scientist. However, in Public Lab's experience, the most powerful voices often come from members who are either intentionally or unintentionally *not* segregated into a specific realm of expertise. Karen Hoffman (2011) wrote a compelling case about organizational scientific experts constructing community voices to have a specific meaning or place in a conversation, rather than allowing for community voices to truly advocate on their own behalf. Her case study centered on the work of the Clean Air and Water Network's (CAWN) attempt to build community organizing as a part of their organizational structure and in response to critiques of environmental groups from within the environmental justice movement, and the opportunities and challenges it presented CAWN. It demonstrated how in the environmental field, there has been a slow progression away from the idea that degreed experts, corporate stakeholders, and government have exclusive rights to voicing ideas in environmental decisions, but this process of deciding who are or are not stakeholders is still largely controlled by experts. Public Lab believes that by deconstructing hierarchies of expertise and equipping people with data and requisite data literacy, people will be able to further communicate and participate as representatives of their own communities and causes.

In case studies such as presented by Hoffman, discussions and decisions in the environmental sector have been based solely on the opinions of the technical or scientific experts in the room (Fisher, 1994). This concept of expertise is so ingrained in public perception that we find situations such as described by Gwen Ottinger (2011) in which engineering students are unable to step outside of their societal embodiment of expertise, even though the students were the ones who were brand new to the issues at hand. Rather than viewing themselves as participants in a community research project, they still had personal identification as the expert (Ottinger, 2011). In a review on arguments around expertise, William Kinsella (2004) noted that this type of nod to the individual with the highest socially defined levels of technical expertise was still problematic, and pointed to Frank Fischer (2000) who argued that technical and scientific expertise should be meshed with local knowledge and contextualization. Public Lab promotes this meshing and demonstrates that expertise is indeed both learned and lived, and that the combination can lead to a stronger understanding of social and scientific conditions. Public Lab also suggests that empowering people with skills and literacy in technologies and scientific processes behind issues they've identified, help to create true stakeholder partnerships, as opposed to having community stakeholders for performative purposes. Low-cost open technology with a collaborative community facilitates integration of different forms of expertise and promotes multi-directional learning for all stakeholders to be better environmental communicators and contributors to environmental decision-making.

Deliberative and participatory democracy

Public Lab works at the intersection of community science, environmental monitoring and open data. Rooted in the OpenGov movement for making the processes and rules of government transparent, open data advocates push toward data accessibility and opening big data for use in innovative or strategic ways by the civic sector. The primary benefit of big data is to be able to understand broader patterns and linkages, however the details of any one situation are not elucidated, and it is often one local situation that is influential over a community's health. Community science advocates for the same openness and accessibility, but a flow of data in the opposite direction. Rather than focusing principally on big sets of environmental information, community science supports the use of grassroots collected, local bodies of data (also referred to as "small data" in some contexts (Pollock, 2013; Warren, 2013; Kavis, 2015) to be used in decision making processes. Corporate and government stakeholders historically have not been open to releasing legible sets of data for common use or integrating community collected information into their processes. Presently, however, requests from government agencies for community groups to fill gaps in data acquisition, the growing momentum behind OpenGov and other open data advocates, and the creation of councils that issue stakeholder seats to community representatives, give hope that democratic participation could become an integrated part of environmental decision making processes.

The OpenGov movement and work contributed by the private and nonprofit sectors has been impactful in encouraging the opening of government datasets and making these datasets legible to the broader public. The development of frameworks to address the increasing contributions of data from the public as a means to fill gaps has also become a way for agencies to be responsive to the increase of data from outside agencies. Examples in the last several years include the Federal Community of Practice on Crowdsourcing and Citizen Science (DigitalGov, 2016) recognition of citizen science, NASA opening access to peer-reviewed papers through their new portal NASA PubSpace, and the recognition of federal funding agencies that communication of data to the public is key. NSF funds superfund centers that are required to have a science communications branch where research translation is part of the process of making research more tangible and usable rather than just technically accessible. Groups working on opening access to corporate data include projects such as OpenOil (OpenOil.net) that attempt to make information from corporations accessible for people to understand.

The term deliberative democracy (Bessette, 1980) connotes systems in which structured votes are used in decision-making processes. A similar form of participatory governance is central to the structure of open communities such as Public Lab through its collaborative, iterative research and development process. In the research and prototype stages, open licensing prompts a system in which deliberation between individuals and parties happens, inherently creating conversations that request collaborative processing. For example, collectively deciding where to map, the type of flying apparatus, or appropriate angle for collecting images, creates a social and technological process in which questioning, discussing and drawing collective conclusions lead to better results. These processes often require significant time commitments and some financial resources as well. One of the challenges facing communities engaging in collaborative community science is that communities facing environmental injustices are also often communities who have minimal resources and capacity to engage in time-intensive collaboration. It is essential to find the unique balance between the depth of involvement and breadth of work distribution that works for each community.

The civic technologies and the community structure that Public Lab supports leverage aptitude changes that harness data, information, skills and environmental literacy, prompting empowerment towards stakeholder involvement in decision-making. One might also suggest that the types of technology that are becoming available for the public, combined with a decrease in resources available to government regulators, could facilitate and even necessitate a place for participatory democratic processes in environmental decision making. The EPA's National Advisory Council for Environmental Policy and Technology is expected to release a 2016 and 2017 report that will outline how community and citizen science can support the work of EPA and allow public participation in agency agenda setting. At the state level, we increasingly see the connection of agency work to citizen monitoring programs such as in the recent case of the Wisconsin DNR allocating funding for 23-organizations that will support water monitoring efforts in the state (Wisconsin DNR, 2016).

Public participation through communication technology

Services such as Twitter and devices such as wearable trackers are rapidly changing the way people participate in environmental communications. However, technology does not serve the needs of people if it is removed from human contextualization or created in a manner disconnected from purpose. In instances such as the One Laptop per Child program, the vast draw of crowdsourcing and crisis mapping, and Internet of Thing modules, we repeatedly see that if tools are not contextualized around lived processes, technology repeatedly fails to serve as a communication amplifier (Toyama, 2015). Rather than relying on technology without context, Public Lab's model of community science utilizes communication technology to support communities in the process of demystifying traditional black box technology, developing community bonds during environmental research processes, and in addressing information accessibility issues, such as creating plain language translations of dense regulatory and legal documents, and contextualization of data sets.

In the following section, we introduce a tiered method in which civic technology, open practices, the unbinding of expertise, and a central focus on community science leads to accessible support mechanisms for communities to assert their causes, filling data gaps, and systems for leveraging organizing practices with the technological means to allow those most affected by environmental decisions the ability to become active stakeholders.

III. PUBLIC LAB'S TIERED PROJECT MODEL

Introduction to the Tiered Model

Community environmental science projects, and environmental monitoring studies in general, can have a variety of ultimate objectives, ranging from personal awareness to federal policy formulation. Projects with different end goals operate on different timelines and require different human, fiscal, and technical resources, and thus require different project design. Public Lab has developed a tiered structure to conceptualize types of projects and the approaches necessary for reaching community goals.

In Public Lab's three-tier model, tiers are delineated by two primary metrics: the role of community science in achieving project outcomes, and the intended scope of those outcomes. Table 1 summarizes the tier categorizations. Tier 1 "Performative Projects" have civic technologies as their centerpiece, but rather than being applied to community environmental concerns, their objectives are usually to generate interest in a technology or space. Performative Projects are often conducted by persons from outside, engaging communities through performance or demonstration. Tier 2 and Tier 3 projects have community application-based objectives. Tier 2 "Community Projects" are projects conducted by community members, entirely supported by community science, and whose impacts will be primarily within that community. Tier 3 "Partner Projects" are projects in which community groups and institutions develop partnerships, where community science is the basis for further investigation by partner groups in order to achieve community goals. Outcomes of Tier 3 projects have impacts within and beyond the community. Within each tier, there are different tracks for projects, based on the type of problem and partnerships necessary. In Tier 1, tracks are distinguished by the platform of performance. In Tier 2, tracks are distinguished by whether the environmental problem is due to a unique event (e.g. an oil spill) or a persistent problem (e.g. noxious gas emissions from a hog farm). In Tier 3, tracks are distinguished by whether the partnerships are governmental, academic, or legal.

Table 1. Public Lab Tier Model for Project Design

Tier	Community Science Role	Outcomes Scope	People Conducting Project	Tracks
Tier 1 Peformative	Primary/Fundamental	Not applied to community goals	Persons outside community	A: Education B: Art C: Technology Interest D: Awareness Raising
Tier 2 Community Project	Primary/Fundamental	Primarily impact community	Community members	A: Individual Event B: Persistent Problem
Tier 3 Partner Project	Basis or screen for other research	Community and beyond	Community members and institutional partners	A: Government (1, 2, 3) B: Academic C: Legal or Lobby

Tier 1: Performative Projects

Performative science can connect the study of science to art (Diebner, 2006). Public Lab has observed the use of performative science as a portion of the learning, teaching, prototyping and exploratory processes used throughout the community. Inclusion in this tiered structure recognizes that performative science holds a distinct introductory place in a model otherwise centered on data collection for specific ends by groups focused on explicit objectives. In this Tier 1 phase, different structure and communication objectives arise. In Public Lab, projects within the performative science tier might resemble a highly visual light-emitting tool in a water body to demonstrate how to "paint" water temperatures through colors of light (Preston, 2015), or the use of balloons in public spaces to visualize urban impacts on wind dynamics (iLAND, 2012). Another inspirational performative science project is the "Aerocene" project led by Tomas Saraceno, creating solar balloons for fuel-less flight, described as, "a traveling sculpture that crosses frontiers between art and science: becoming a visionary open participatory platform" (Saraceno, 2016). In the performative use of tools, built for the purpose of environmental monitoring, creative expression is at the forefront of participation with and in the environment.

Problematically, it is often unclear if the performative purpose is known to participants during the process of demonstrating a tool or looking at visual data. For example, people may be unaware that a tool used to visualize temperature may not be accurate or precise, and may not have been designed to produce quality data. If the purpose is unclear, there are several indicators that a demonstration or exercise is likely to be fundamentally performative. The first is that people conducting the process have typically selected a site non-specific to a focused environmental research question created by a community. The second is that the process will often involve researchers interested in exploratory learning, rather than application. A third indicator is a focus on the process of visualization rather than in visualizing usable data; the creative process is the primary objective in this type of performative science. Finally, the prototyping and testing of tools in a performative setting often centers on exploration and connecting people to the process of tool design, experimentation and visualization of information. This becomes the emphasis instead of making systematic iterations toward more accurate and precise tools.

Performative science can also happen in unintentional ways. The balloon tool of Public Lab is an important device for aerial image data collection, but with bright color and 5.5 foot diameter it also can create visibility and transparency in data collection processes. This transparency can ease tensions that can be present in the process of community data collection. For instance, after the BP oil spill in 2010, author Dosemagen spent time in areas throughout the coastline of Louisiana collecting images of oiled beaches and wetlands in several locations. Each stop warranted a "pull over" by contractors running the cleanup, interested in knowing who we were and what we were doing. A large, floating red balloon, despite a specific description that it carried a camera meant to capture images of the wetlands, was seen as unthreatening and even humorous. In this instance performative science seeped into the process of a community science project.

Tier 1 performative science can be valuable in environmental communication as it can help call attention to or generate interest in a specific topic or location. The focus on visuality of the process of tool creation and data collection can be a compelling way to bring new people to a project. When moving into Tier 2, where there are tangible community goals beyond engagement, we caution that a consistent state of performative science can cause project momentum to regress and sometimes cause a power dynamic between communities and bearers of performative tools. With particular objectives and issues to address, elongated acts of performance can disengage community researchers if usable data isn't collected in the process.

Tier 2: Community Projects

Public Lab and community science projects are predicated on disrupting institutionalized hierarchies of production and access to knowledge in order to create space for public exploration and investigation. Disruption can provide compelling ways for spaces to reflectively change portions of a model that might not be completely addressing the needs of all potential stakeholders (Christensen, 2013; Kuhn, 1996). In Public Lab Tier 2 and Tier 3 projects, community members not only participate, but also initiate and conduct projects. This is a key distinction between older models of citizen science and the community science practiced in Public Lab. Truly democratic civic and community science requires access to tools that are affordable to individuals and communities, and the requisite support for tool usage and data analysis. Philanthropic organizations have provided financial support for community science endeavors, but securing perpetual funding through public means would be preferable, and reducing financial requirements is essential. Advances in low-cost consumer technologies such as digital cameras and microcontrollers (e.g. Arduino Uno and Raspberry Pi), wireless and cellular routing systems, and the rise of open source and peer production cultures are fundamental to civic science, community science, and Public Lab.

Community Projects (Tier 2) are conceived and implemented by a community using available tools and methods, and with project outcomes that primarily impact the community. A community's capacity to engage with community science is greatly enhanced through the open source movement, particularly the emergent field of open hardware. With open access to tool designs, cost-conscious design principles, and support for DIY endeavors, communities can utilize civic technologies. Civic technologies provide learning opportunities for enhanced understanding of tool and technique capabilities and limitations, which are essential to data literacy. Harnessing the power to collect, interpret and share their own data, without relying on industry or government, allows communities a more autonomous voice in their proceedings. Free online data repositories such as MapKnitter (mapknitter.org) and Open Science Framework (osf.io) help make this possible. Open access to data, effectively removing it from the clandestine confines of industry or government internal documents, walled often for financial gain or fear of liability, is in essence a protest against the status quo. Open and contributory data features such as editable wikis also provide a web-based platform where community members can speak their truth. However, there remain accessibility issues for many people to participate in open online platforms, as it requires Internet access and substantial computer literacy. To address this sort of digital divide in Public Lab in-person community tool construction and use, discussions, and advocacy work are essential to the fabric of the community too.

There are two tracks of Tier 2 projects requiring different study designs, timelines and advocacy strategies: Track A for unique individual situations or events, and Track B for pervasive or endemic issues. Track A event-based research may also reveal persistent issues that require Track B community research. Due to the fact that Tier 2 projects are conducted by communities themselves, they can proceed along a variety of timelines. With successful community organizing, Tier 2 projects can capitalize on community momentum, and mobilize on short notice for public engagement or rapid response to crises. Tier 2 projects can also offer consistency for successful long-term monitoring and recurring studies, with less transient researcher populations than other types of projects may expect. Project design will be significantly different for the two categories of projects, and the monitoring and advocacy strategies involved will also be sensitive to community access to significant locations, whether or not communities are recognized as established or aspiring stakeholders, and what sort of human and financial resources are available in communities.

Project design and intended outcomes are largely dependent upon the known data quality capabilities and limitations of the tools and techniques employed. For example, if a community is interested in monitoring salt water intrusions into freshwater marshes near the coast, the accuracy and precision of their conductivity sensors will dictate whether they pursue a qualitative or quantitative study, and whether they could utilize the results of the study to raise community awareness or to more directly address operations contributing to the issue, such as dredging for industrial canals. The sophistication of data collected through civic and community science has been augmented through advances in consumer technologies (e.g. microcomputers) allowing for low-cost electronic sensor data collection and advances in wireless communications enabling remote data access. Consumer technologies such as the Air Beam (http://aircasting.org/) utilize these advances and have created widely available tools. Most civic technologies do have substantial limitations with instrument sensitivity or selectivity though, especially relative to institutional technologies. Data limitations in civic technologies are partly why Tier 3 projects can be necessary to obtain certain community objectives. Photography is one area in which civic technologies are on par with institutional technologies, especially with requisite data chain-of-custody documentation for photographs' date, time, and location now embedded in cellular phones. Community-collected photographs are some of the most prevalent and effective community science data for projects with a variety of subject matter, and for a wide range of project objectives.

Through Tier 2 projects, community members are able to accomplish an array of outcomes, including specific outputs and changes such as:

- Community centered knowledge production and sharing
- Data literacy
- Media engagement
- Stakeholder engagement
- Ecosystem management
- Community behavioral change
- Skills enhancement
- Partnership development

In addition to direct community impacts, Tier 2 Community Projects may also provide results that warrant further investigation in the regulatory or legal realm, and thus transform into Tier 3 Partner Projects.

Tier 3 Partner Projects

Partner Projects (Tier 3) utilize community science as a basis for further investigation through institutional means, involve partnership development between communities and other establishments, and have intended project outcomes with impacts within and beyond participating communities. As with Tier 2 projects, Tier 3 projects are community-driven, with the community-identified need becoming central to institutional endeavors through these projects. The structure of partner projects will depend on multiple variables including the category of partner, project funding, the capabilities and limitations of civic technologies used, and community goals. The distinguishing marks between a Tier 3 Partner Project and a more traditional study or investigation are that (1) community-identified objectives are the focal points, (2) community science plays a pivotal role in the overall study, often as an indicator or screening method, and (3) the community invites the partners, rather than researchers using community groups as cheap labor or research subjects. The community data based appeal and active collaboration in Tier 3 projects provides a new avenue for dynamic public participation in environmental research and decision-making, where communities participate throughout the process.

There are three tracks in Tier 3 Partner Projects, distinguished by the type of partner institution, and three substantially different sub-tracks for government partnerships with different objectives:

- Track A: government agency

a) Track A-1: local government agencies to address specific studies and issues

b) Track A-2: state agency or regional EPA to address broader issues

c) Track A-3: state and federal agencies with objectives related to the role of community science and communities as stakeholders

- Track B: academic or other professional research institution

- Track C: legal firm or lobby.

Government partner projects (Track A) may become the most frequent, and perhaps most fruitful, type of Tier 3 project. In recent years, the US EPA has begun to acknowledge and encourage citizen science through initiatives like Next Generation Air Monitoring and federal advisory councils including the National Advisory Council on Environmental Policy and Technology and the National Environmental Justice Advisory Council. However, it is important to clarify that the citizen science programs and projects currently supported by the EPA are agency-driven, where citizens participate in EPA projects to pursue EPA research objectives, rather than community-driven projects utilizing civic technologies to address community concerns. Emphasis on community involvement and community-relevant outcomes in the EPA's Environmental Justice strategic plans for upcoming years (EPA EJ 2020 Action Agenda Framework, 2015), could engender opportunities for developing Tier 3 Partner Projects, bringing community environmental justice goals to the forefront of research and remediation projects.

Partner Projects have the opportunity to be mutually beneficial. Currently, as government funding for environmental agency work is limited, especially in the enforcement sector, routine monitoring and enforcement investigations are sparse, and too often community concerns go unaddressed. For environmental permit enforcement or restructuring for local or regional issues, for example, utilizing community-collected data as a screening tool could benefit all parties because it would increase efficiency for agencies and more adequately respond to the plethora of community environmental concerns. Several citizen science projects such as the CoCoRaHS (Community Collaborative Rain Hail & Snow) meteorological monitoring network demonstrates the viability of utilizing community-collected data to inform agency research. Community-centered focus in initiatives in the EPA's Sustainable and Healthy Communities Program demonstrates the interest in prioritizing community needs. Pathways to true partnership for communities and government agencies based on community-collected data are possible, and necessary.

Community commitment to open science and open data can facilitate the acknowledgement of community science as providing relevant data. Included in the open data platform, specific data collection protocols and instrument parameters should be delineated, and raw data and transformed data sets should all be included so that there is explicit transparency in the community science data quality. Without laboratory accreditation for community science, extreme transparency and clear communication are necessary for building trust and demonstrating legitimacy to potential institutional partners or critics. One of the areas for which it is most important to communicate clearly, especially during partnership development, is the intended purpose of different techniques. At present, only a few civic technologies and techniques have similar capabilities as regulatory methods, such as the Public Lab aerial mapping kit, and therefore data quality expectations of specific civic technologies, and moreover the capabilities and limitations of data produced, must be clearly and openly discussed. In 2014, the EPA Office of Research and Development evaluated the accuracy and precision of several low-cost air monitors, and while none of the monitors performed like regulatory methods, the authors did postulate that there could be applications in which various low-cost instruments could be useful depending on their data quality (Williams et al, 2014). Two potential use-cases for low-cost air monitors could be as indicator methods and "hotspot" pollution screenings. Public Lab developed a similar model for applicable use-cases dependent upon methods and data quality that are relevant to Public Lab projects (Gehrke et al, 2015) and is developing a dynamic system to clearly label the level of intended use of the fully developed tool or method, and the current status of the tool or method in development. This is a challenge in open, dispersed contributory development, without a necessarily linear or confined development path, but will foster transparency and enable clear communication.

While in community science and civic technology openness and transparency are fundamental and essential to their existence, and are useful in developing trust and an understanding of data capacity in various projects, the openness of data subsequent to partnership development is likely to require thoughtful discussion between partner groups. Although there is a shift happening towards open practices, research institutions and government agencies often do not adhere to open data principles, be it for concerns over intellectual property or liability, while it is the lifeblood of civic technoscience. Public Lab advocates for open data and transparency, especially when that best serves the community objectives.

With appropriate forthright communication, partnerships between communities and government or research institutions can be established, as has been demonstrated in a variety of community-based participatory research partnerships. Low-cost civic technologies often can provide the opportunity to partially fill in data gaps where expensive or cumbersome monitoring equipment is not feasible, or substantially increase the data density for a project (i.e. provide more sensors and data collectors), enabling more comprehensive studies to address community concerns. The use of low-cost technologies by community researchers has demonstrated this principle of enhanced data density in many citizen science projects, such as CoCoRaHS and iNaturalist, and demonstrate the potential for community-collected data to support research that directly addresses community concerns too.

Partner projects with lobby groups or legal entities may have different development pathways than those with government or academic institutions. Discussions around community data quality are possibly even more important in Track C than in the other tracks because it is quite possible that the only data collected explicitly for the given project are the community science data. A legal or lobby partner project's further investigation may involve research into historic permit and pollution records, or other relevant information such as a company's financial obligations or political contributions. In two discrete cases, Public Lab aerial imagery has been pivotal to pre-litigation legal proceedings to successfully pressure companies to clean up their practices and comply with their permit requirements. Community science and community observations are fundamental to the success of legal or lobby partner projects as they provide witness to the offense. Partner projects in the legal realm can have some of the most impactful outcomes for communities, including the most direct outcomes such as requisite environmental remediation, and setting legal precedent for community-collected data admissibility.

All tracks in Tier 3 projects are likely to be long-term projects and processes. Partnership development requires substantial time in order to build trust among all partners, agree to memoranda of understandings, obtain funding, and possibly obtain clearances such as an Internal Review Board (IRB) approval. To achieve the intended outcomes of this style of project also requires time, as regulatory and legal proceedings often take years. Partner projects are not appropriate for rapid response situations unless a partnership is already existent.

Community partnerships with various institutions can provide avenues for community science practitioners to participate in tangible ways in environmental research and environmental decision-making. Mutually beneficial partnerships can produce more comprehensive knowledge production and effective application to address community-identified needs than either entity could accomplish without the partnership. The potential outcomes of Tier 3 Partner Projects are potentially large and cascading, including:

- Regulatory permit enforcement
- Regulatory permit revision
- Environmental remediation
- Litigation
- Investigative media engagement
- Policy adaptations
- Formal information sharing (e.g. reports and articles)

In this section, ways in which community science amplifies the ability for people to effectively communicate about the environment-- through performance (Tier 1), community projects (Tier 2) and partner projects (Tier 3)-- has been mapped out to demonstrate the types of relationships and outcomes possible. In the next section, case studies to illustrate relationships in the three tiers are discussed.

IV. CASE STUDIES

Performative Science (Tier 1)

Performative science has been used in the Public Lab community to pique interest in common water quality concerns and recruit contributors to water sensor tool development. The Coqui is a circuit board that relays measured resistance (which could be a measure of water conductivity, for example) to an audio output (Blair, 2014). Transforming resistance to audio frequency allows the sensor to be interpreted by phone and computer, and also makes demonstrative sounds that are useful in making an abstract concept like conductivity more tangible. Data resolution is lost in this conversion, and there are more efficient data transformation approaches, but the Coqui was specifically designed with an audio output for educational and engagement purposes -- performance is a conscious part of the design.

With the audio jack in place, audible squeals evolve from the Coqui when it is placed in water, and the pitch of the squeal is related to water conductivity -- the higher the pitch, the higher the conductivity of the water. The tool does have several potential use-case scenarios after minimal further development, including observing effects of road salt application on nearby rivers or monitoring salt-water intrusions along canals and bayous. However, in its current status, the Coqui is primarily a tool used to generate interest in technology and perhaps environmental issues. The Coqui has been used to engage multimedia artists, students in introductory circuit board design, and hydrologists, and is a base technology for further conductivity sensor developments in Public Lab.

A poignant example of using the Coqui in performative science is Professor Catherine D'Ignazio's workshop with students at Middlebury College, in which students learned about water chemistry through audio signals emanating from the electronic Coqui boards which they had constructed (D'Ignazio, 2016). After constructing the Coquis and experiencing the audio signals associated with different water salinities, the students then used those audio signals to create comedic characters. D'Ignazio's objective in the workshop was to engage students to interact with science and the environment in an unconventional and unintimidating fashion, and thereby acquire a unique perspective and deeper understanding than they previously held. Students engaged in critical making and further hands-on science learning. While the lasting impacts of this engagement are as yet unknown and intangible, the primary outcome that was certainly achieved, as designed and implemented by the professor, was participant engagement through sensory means: performative science.

Community Project

Community projects are conceived of, conducted by, and consequential to communities. Owing to the focus within communities themselves, dynamics of community projects can be similar in a variety of cultures, more so than in Tier 3 partner projects, which are more influenced by political and regulatory structures. An apt example of a community project was conducted by the residents of Bourj Al Shamali Refugee Camp in southern Lebanon. For that community to effectively plan community-enriching, vital green spaces amidst the dense urban settlement, understanding the current distribution of resources and space within the camp is essential (Clauds, Firas and Mustafa10, 2015).

Bourj Al Shamali was created in 1948 as a temporary relocation space for Palestinian refugees after the creation of Israel. Nearly 70 years later, the camp has had a 5-fold increase in population to more than 20,000 inhabitants, and is a densely populated urban environment. Community members are advocating for the camp's first public green space and an urban agriculture initiative to promote health, sustainability, and historic cultural connectivity within the camp. To design and repurpose green spaces, residents needed to visualize the current space and reimagine its potential. They decided to undertake a community aerial mapping project and talked with their long-time friend Claudia Martinez Mansell. Martinez Mansell, while not a resident of Bourj Al Shamali, first became ingrained in the community 18 years ago as a teacher, and is considered a member of the community by many. She has lived and worked with people in Bourj Al Shamali several times over the years, including doing many photographic documentation projects with other community members there. Discussions with Bourj Al Shamali community leaders and Martinez Mansell about the utility of aerial mapping led to inquires about geographic social constructs and interactions, such as the distribution of resources and locations of fire-fighting hubs, and also about the social impacts of community creation of a map utilizing civic technology. Ultimately, community leaders asserted three goals for the Bourj Al Shamali community aerial mapping project beyond physical map production: to increase visibility and awareness of issues, to create dialogue between community members and working groups, and to improve conditions in the camp through this visibility and dialogue.

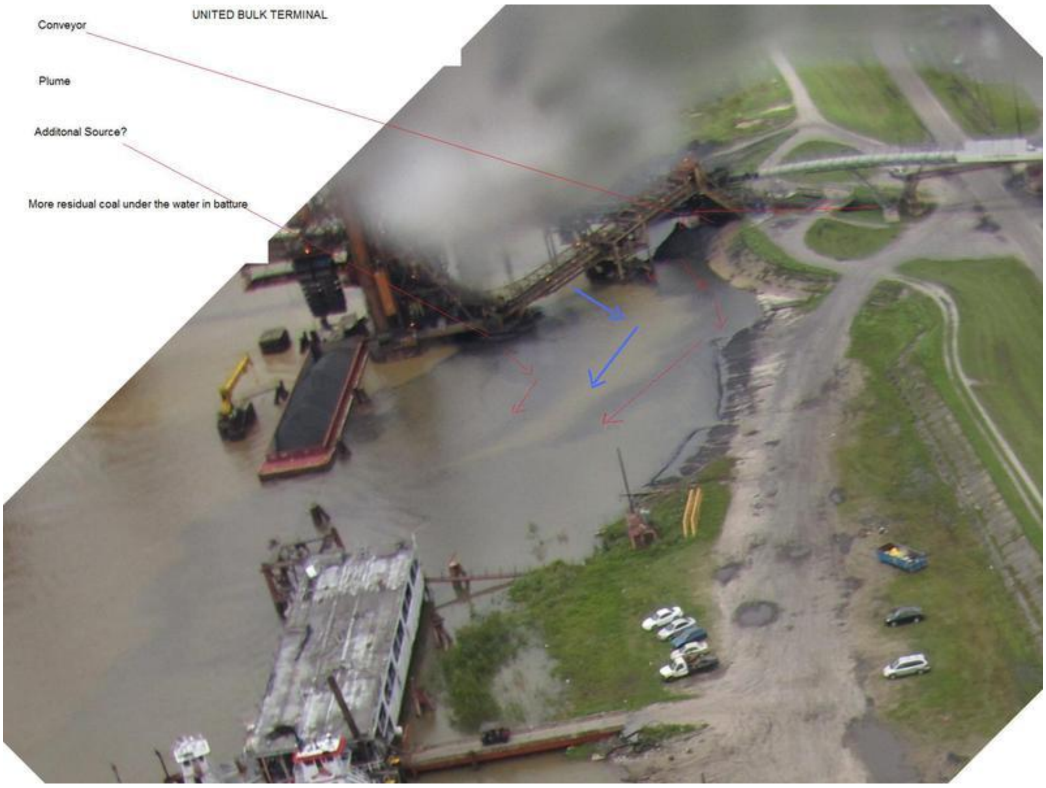
In 2015, Bourj Al Shamali community members and Claudia Martinez Mansell used Public Lab balloon and kite mapping kits to take aerial photographs of the camp, and are producing the first aerial map of Bourj Al Shamali. Community members became involved in the project in multiple ways, from mapping to patching tattered balloons, to inviting community mappers onto their roofs for better aerial access. By the end of the mapping project, the whole community was aware of the project and its purpose. When ready, the maps will first be locally accessible, in print, to be utilized by the community in their green space initiative. Ultimate success of the project will be evaluated on how well it enabled the Bourj Al Shamali community to create green spaces and improve camp conditions.

Partner Project

The following Tier 3 case illustrates a partnership between community members, local organizations and national nonprofits, and the creation of a coalition and partnership with a legal clinic. What started as a Tier 2 Community Project focused on halting development of a specific new coal terminal facility in Ironton, Louisiana, developed into a Tier 3 Partner Project as a coalition formed to not only halt the single coal terminal development, but also to stop expansion and construction of similar facilities in nearby communities with similarly fragile wetland ecosystems. The coalition and partnership included community members in Ironton and neighboring areas; local, regional, and national nonprofit organizations Louisiana Environmental Action Network, Gulf Restoration Network, and Sierra Club; and Tulane Environmental Law Clinic. Ultimately, this partner project resulted in a legal settlement and stakeholder participation by the coalition with the polluting facility.

In 2012, a coal operation, RAM Terminals began steps towards a new coal export terminal facility next to a historically African-American neighborhood, Ironton, in Plaquemines Parish, Louisiana, which already had two coal terminals. Problematically, the proposed new terminal would be the first major railway connector in the area and would also threaten wetland restoration plans in the ecologically sensitive area. Communities adjacent to the proposed RAM terminal and local environmental nonprofits, Louisiana Environmental Action Network (LEAN) and Gulf Restoration Network (GRN), worked together to begin advocating against this export terminal, and local members of the national nonprofit Sierra Club also joined forces. In this combined effort through the "Coasts Over Coal" initiative of GRN and "Beyond Coal" initiative of Sierra Club, communities and organizations also began advocating against the expansion of others coal terminals along the Mississippi River that would be disruptive to wetlands. One of the terminals the environmental organizations sought to halt expansion of was the United Bulk Terminal, a chronic polluter of the River, next to the African American community of Davant, and the communities of Wood Park and Myrtle Grove (Gulf Restoration Network, 2015). This company was a nuisance to local air and water quality and an example of the kinds of wetland contamination RAM would inflict upon the wetland restoration. To document visible violations of operations permits, notably direct waste input from the United Bulk Terminal into the River, GRN and Sierra Club members flew a 9-foot kite equipped with a digital camera to capture oblique aerial images. Through this aerial photography, the coalition was able to capture compelling data that demonstrated the polluting facility activities.

Scott Eustis, Wetland Specialist at GRN called the use of this data, "a critical turning point in our understanding of the problems with United Bulk's dock. With the kite, we saw a very close side view for the first time. The pile accumulating beneath the conveyor showed that the conveyor was moving material directly into the river, over multiple days. The accumulation into the form of the pile showed that this was a systemic problem related to their equipment, not some fluke of a shift worker or the wind" (Dosemagen personal communication, 2016).



Kite aerial photograph taken by Scott Eustis (GRN) and Devin Martin (Sierra Club)

This partnership between community groups, local nonprofits and branches of national green organizations with photographic data in hand was able to prompt a consent decree from the Louisiana Department of Environmental Quality, including fines of $16,000 (United States District Court for the Eastern District of Louisiana, 2015). Unhappy with the terms of the decree, the nonprofit organizations, as members of the Clean Gulf Commerce Coalition, approached the Tulane University Environmental Law Clinic to sue United Bulk, under the citizen suit provision of the Clean Water Act.

In August 2015 this suit was settled for stricter pollution prevention terms, further containment and cleanup activities by United Bulk, and additional fines of $75,000, which have benefited the Woodlands Conservancy to restore wetland forest felled by Hurricane Katrina. As Eustis notes, "United Bulk Terminal agreed to hire more cleanup personnel, spray piles to suppress wind blown dust and vacuum spilled material from the river (all which they were supposed to be doing since 1984), in addition to overhauling the high elevation belt to an enclosed system." Additionally he notes that, "the Clean Gulf Commerce Coalition now interacts with the company directly. If future violations are seen, an official, documented discussion will occur whereby the company will explain the cause and remedial steps and pay supplemental fines" (Dosemagen personal communication, 2016).

Prompting enforcement of the Clean Water Act with community-collected data used in this civil suit against United Bulk Terminal has now set precedent for future community documentation of permit violations to have tangible consequence, particularly when partnered with an organization with legal expertise. Additionally, a model of collaboration between community members, local government officials, and advocacy nonprofit organizations has effectively halted expansion and delayed new construction of coal terminals in Plaquemines Parish for more than three years, demonstrating the power of collaborative organizing, keeping community goals at the heart of the project, and utilizing national networks and regional leverage points.

V. Conclusion

From its grassroots beginnings as a community-driven response to the BP oil spill in 2010, Public Lab has practiced open and participatory environmental science and monitoring in pursuit of community-identified needs. Public Lab's model of community science is designed to be accessible and reproducible, is rooted in the open source movement, and ascribes to transparency, cooperation, collaboration, iterative development, and deliberative democracy. The open frameworks that Public Lab uses are how practices are able to spread in a way that provides a concrete foundation for others to build and modify to better fit specific needs. Community science is participatory throughout the entire project and data lifecycle, from idea generation or need identification, through data collection using civic technologies, to data analysis and application for community objectives. Public Lab's combination of Do-It-Yourself ethos and technologies with a hybrid online-offline community structure empowers community members through the education and confidence inherent in critical making, and also through support from its massive geographically dispersed open science online network. Effective community science builds more capacity in communities to actively engage in environmental research, policy discussions and more.

The authors have introduced a tiered approach to project definition and design for community science projects, based on the role of open civic technologies and potential partnerships necessary for achieving community objectives. Tier 1 consists of projects for performative science that are useful in engaging the public and inspiring interest in civic science, but are outside the realm of true community science because they are not in pursuit of community goals. Tier 2 is comprised of community projects that are conceived of and conducted by community members utilizing civic technologies to achieve community-relevant outcomes. Tier 3 involves partner projects in which communities and institutions (government, academic, or legal) develop partnerships based on community science data that warrants further investigation using professional technologies, and where partnerships are maintained with a synergistic ethos and commitment to collaboratively addressing community concerns. The realization of Tier 3 partner projects require the restructuring of traditional roles of expertise to facilitate multi-directional learning and public participation in decision making and has some of the most potential for impactful work in the future.

Community science is indeed challenging traditional modes of environmental monitoring, investigation and communication. Case studies exemplifying Tier 2 and Tier 3 projects provide evidence that community science does facilitate participation in pursuit of in environmental decision-making and the propensity to achieve community-identified environmental outcomes thereby engaging in environmental decision-making processes. Traditional stakeholders and authorities could also facilitate public participation through reimagining their role and inviting collaboration with communities. Short of that unlikely occurrence, empowering communities to collect and interpret their own data, with openness and transparency, demands public engagement and participation and will ultimately add community voices to the conversation.

Artigo recebido em 31/01/2017 e aprovado em 11/05/2017.

REFERENCES

Ashkenas, R. (2015). *There's a Difference Between Cooperation and Collaboration. Harvard Business Review*. Retrieved from Harvard Business Review: https://hbr.org/2015/04/theres-a-difference-between-cooperation-and-collaboration

Bessette, J.M. (1980). Deliberative Democracy: The Majority Principle in Republican Government. *In* R.A. Goldwin & W.A. Schambra (Eds.), *How Democratic Is the Constitution? (*pp.102-116) Washington: American Enterprise Institute for Public Policy Research.

Bilton, N. (2010). *Taking on the Gulf Oil Spill with Kites and Cameras*. Retrieved from the New York Times: http://bits.blogs.nytimes.com/2010/06/09/hacking-the-gulf-oil-spill-with-kites-and-cameras/?_r=0

Blair, D. (2014). *Coqui BBv1.0*. Retrieved from Public Lab: https://publiclab.org/notes/donblair/09-30-2014/coqui-bbv1-0

Christensen, Clayton. (2013). *The Innovator's Dilemma: When new technologies cause great firms to fail*. Cambridge: Harvard Business Review Press.

Clauds, Firas and Mustafa10. (2015). *Lessons from Mapping Bourj Al Shamali Refugee Camp in Lebanon*. Retrieved from Public Lab: https://publiclab.org/notes/claudsmm/08-23-2015/lessons-from-mapping-bourj-al-shamali-refugee-camp

Coleman, G. (2013). *Coding Freedom: The ethics and aesthetics of hacking*. Princeton: Princeton University Press.

Collins, H. (2014). *Are we all scientific experts now?* Cambridge: Polity Press

D'Ignazio, C. (2016). Environmental Data Comedy Workshop at Middlebury College. Retreived from PublicLab.org: https://publiclab.org/notes/kanarinka/01-22-2016/environmental-data-comedy-workshop-at-middlebury-college

Diebner, H.H. (2006). Performative Science and Beyond: Involving the Process in Research. Vienna: Springer Vienna Architecture.

DigitalGov. (2016). Federal Crowdsourcing and Citizen Science. Retrieved from DigitalGov: https://www.digitalgov.gov/communities/federal-crowdsourcing-and-citizen-science/

DiSalvo, C. (2009). Design and the Construction of Publics. Design Issues, 25(1), 48-63.

Dosemagen, S. (2016). Personal communication with Scott Eustis between April and August 2016.

Eaves, D. (2014). *Building Power Through Data Sharing: Issues and opportunities for environmental health and justice funders*. Retrieved from Health and Environmental Funders Network: http://www.hefn.org/learn/resource/building_power_through_data_sharing_issues_opportunities_environmental_health_justice

Environmental Protection Agency. (2015). *Draft EJ 2020 Action Agenda Framework*. Retrieved from EPA.gov: http://www3.epa.gov/environmentaljustice/resources/policy/ej2020/draft-framework.pdf

Epstein, S. (1995). The Construction of Lay Expertise: AIDS activism and the forging of credibility in the reform of clinical trials. *Science, Technology and Human Values*, 20(4), 408-437.

Fischer, F. (2000). Citizens, Experts and Environment: The politics of local knowledge. Durham: Duke University Press.

Fisher, W.R. (1987). Human Communication as Narration: Toward a philosophy of reason, value and action. Columbia: University of South Carolina Press.

Fortun, K. and Fortun, M. (2005). Scientific Imaginaries and Ethical Plateaus in Contemporary U.S. Toxicology. *American Anthropologist* 107(1), 43-54.

Gehrke, G., Warren, J., Dosemagen, S., Blair, D. (2015). *Intended Purposes for Different Tools and Techniques*. Retrieved from Public Lab: https://publiclab.org/notes/gretchengehrke/10-07-2015/intended-purposes-for-different-tools-and-techniques

Gulf Restoration Network. (2015). *The Fight Against the RAM Coal Export Terminal*. Retrieved from Gulf Restoration Network: http://healthygulf.org/our-work/energy-climate-change/coast-not-coal

Hoffman, K. (2011). From Science Based Legal Advocacy to Community Organizing: Opportunities and obstacles to transforming patterns of expertise and access. In G. Ottinger and B.R. Cohen (Eds.), *Technoscience and Environmental Justice* (pp.41-62). Cambridge: MIT Press.

Howe, J. (2006). *The Rise of Crowdsourcing*. Retrieved from Wired: http://www.wired.com/2006/06/crowds/

Interdisciplinary Laboratory for Art Nature and Dance. (2012). *iLab Residency Archive*. Retrieved from iLab: http://www.ilandart.org/ilab/higher-ed/

Kavis, M. (2015). *Forget big data-- small data is driving the Internet of Things*. Retrieved from Forbes: http://www.forbes.com/sites/mikekavis/2015/02/25/forget-big-data-small-data-is-driving-the-internet-of-things/#2715e4857a0b2cc03ad9661b

Kinsella, W.J. (2004). Public Expertise: A foundation for citizen participation in energy and environmental decisions. In S.P DePoe, J.W. Delicath and M.F.A. Elsenbeer (Eds.), *Communication and Participation in Environmental Decision Making* (pp. 83-95). Albany: State University of New York Press.

Kelty, C. (2008). *Two Bits: The cultural significance of software*. Durham: Duke University Press.

Kuhn, T. (1996). *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press.

Latour, B. (1987). Science in Action: How to Follow Scientists and Engineers through Society. Cambridge: Harvard University Press.

McClintock, A. (2012). Slow Violence and the BP Spill Crisis in the Gulf of Mexico: Militarizing Environmental Catastrophe. *Hemispheric Institute E-Misferica*. Volume 9.1-9.2. Retrieved from: http://hemisphericinstitute.org/hemi/en/e-misferica-91/mcclintock

Ottinger, G. (2011). Rupturing Engineering Education: Opportunities for transforming expert identities through community-based projects. In G. Ottinger and B.R. Cohen (Eds.), *Technoscience and Environmental Justice* (pp. 229-249). Cambridge: MIT Press.

Phillips, M. (2010). *Photographers say BP restricts access to oil spill*. Retrieved from Newsweek: http://www.newsweek.com/photographers-say-bp-restricts-access-oil-spill-72849

Peters, J. (2010). *Efforts to limit the flow of spill news. Retrieved from New York Times*: http://www.nytimes.com/2010/06/10/us/10access.html?pagewanted=all

Pollock. (2013). *Forget Big data, small data is the real revolution*. Retrieved from Open Knowledge Blog: http://blog.okfn.org/2013/04/22/forget-big-data-small-data-is-the-real-revolution/

Preston, E. (2015). *Handmade Boats Bring Citizen Science to the Mystic River*. Retrieved from the Boston Globe: http://www.betaboston.com/news/2015/09/16/handmade-boats-take-tour-of-citizen-science/

Ratto, M. (2011). Critical Making: Conceptual and material studies in technology and social life. *The Information Society* 27(4), 252-260.

Resnick, M., Berg, R., Eisenberg, M. (2000). Beyond Black Boxes: Bringing transparency and aesthetics back into science. *Journal of the Learning Sciences* 9(1), 1-21.

Saraceno, T. (2016). *Aerocene*. Retrieved from: http://www.aerocene.com/

Shirk, J. L., Ballard, H. L. Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B. V., Krasny, M. E., and Bonney, R. (2012). Public participation in scientific research: a framework for deliberate design. *Ecology and Society* 17(2): 29.

Sutter, J.D. (2010). *Citizens Monitor Gulf Coast after Oil Spill*. Retrieved from CNN: http://www.cnn.com/2010/TECH/05/06/crowdsource.gulf.oil/index.html

Toyama, K. (2015). Geek Heresy: Rescuing social change from the cult of technology. New York: PublicAffairs.

United States District Court for the Eastern District of Louisiana. (2015). *Consent Decree: Gulf Restoration Network, et al. v. United Bulk Terminals Davant, LLC - Case 14-cv-00608*. Retrieved from: https://drive.google.com/file/d/0B9TzfQJ7Qw4GcHdFMkVzM1NXbkxJV1p5bXo0aHp6RnIzS2p3/view

Warren, J. and Dosemagen, S. (2011). *Reimagining the Data Lifecycle*. Retrieved from Public Lab: https://publiclab.org/notes/warren/07-01-2014/reimagining-the-data-lifecycle

Warren, J. (2013). *The Promise of 'Small' Data*. Retrieved from TechPresident: http://techpresident.com/news/24176/backchannel-promise-small-data

Williams, R., Kilaru, V., E. Snyder, A. Kaufman, T. Dye, A. Rutter, A. Russell, and H. Hafner. (2014). *Air Sensor Guidebook*. Washington, DC: U.S. Environmental Protection Agency.

Wisconsin DNR. (2016). DNR funds volunteer monitoring efforts. Retrieved from Wisconsin DNR: http://dnr.wi.gov/news/Weekly/Article/?id=3672

Wylie, S., Kirk, J., Dosemagen, S., and Ratto, M. (2014). Institutions for Civic Technoscience: How Critical Making is Transforming Environmental Research. *The Information Society, Special issue: Critical Making as Research Program*. 30(2),116-126.