Mapping Grassroots: Geodata and the structure of community-led open environmental science

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Abstract

Grassroots Mapping, an early project of the Public Laboratory for Open Technology and Science, began in 2010 in Lima, Peru. Using balloons and kites to launch cameras as "community satellites", grassroots mappers around the world have engaged in local-level, activist remote sensing -- building upon the critical cartography and participatory mapping movements to investigate local environmental and social issues with inexpensive "Do-It-Yourself" technologies. This article discusses community participation models and the importance of high-level participation in avoiding what we term *crowdharvesting* -- a widespread trend in contemporary citizen science projects where participants are limited to categorizing data or logging observations. By contrast, through the process of first-hand data creation and analysis, community researchers in the Public Lab network have attempted to build expertise, critique existing data collection regimes, and reconfigure techno-scientific processes to include substantive civic participation.

Introduction

The Public Lab community was founded in 2010 in New Orleans, in response to the Deepwater Horizon oil disaster in the Gulf of Mexico, and has grown to include a network of several thousand informal environmental researchers from a variety of backgrounds. Members of the community span from academic researchers in chemistry, toxicology, and the history of science to concerned residents of pollution-affected areas and technology "hackers" from the emerging *maker* movement. While these individuals have diverse motivations, a central goal of the community, as stated on PublicLab.org, is to "research open source hardware and software tools and methods to generate knowledge and share data about community environmental health". A team of staff employed by the non-profit organization, also called Public Lab, provide online infrastructure, fund raise for Public Lab projects, distribute testing kits, and organize frequent regional and international events (three of the authors are co-founders of the non-profit). The environmental monitoring tools Public Lab produces, however, are primarily built through the contributed research of members, who share their work on the PublicLab.org website.

Using the website as well as regional and topical discussion lists, members identify environmental issues, brainstorm and prototype affordable means of monitoring specific pollutants, and collect environmental data, which is often also shared on Public Lab's websites. By releasing hardware designs, software, and data under open source licenses, contributors provide legal permission for others to make use of these technologies and data, so long as any adaptations or improvements are then shared under the same license, in what is referred to in the free culture movement as *copyleft* or *share-alike* licensing. The ideals and conventions of the open source movement are beyond the scope of this article, but open source software projects have been able to produce complex tools and technologies including operating systems and web browsers, which are created by geographically distributed communities of largely volunteer contributors, and are freely available for the public to use, adapt, modify, and redistribute. It is within this framework that Public Lab's founders hope to engage various actors in the co-creation of affordable monitoring tools.

The Public Lab approach attempts to respond to the tendency of laboratory-based research to favor the socially and economically powerful, and the failure of such research to integrate the perspectives of underserved populations (Murphy, 2006; Allen, 2001; Fortun and Fortun, 2005). Public Lab's organizers have sought to develop alternative processes for research and development centered around environmental justice and environmental health issues that enable lay practitioners to get involved in, and ideally direct, the questioning of 'the state of things'. Public Lab is focused on creating an open space where participants are able to work within the "full data lifecycle" (Dosemagen and Warren, 2011) of the scientific process; identifying and creating points of entry that are applicable to their interests. As an organization, Public Lab works towards engaging and empowering people to enter the approach of, for instance, an aerial mapping project at the point (or points) that will instill a sense of ownership over normally exclusive and non-engaged scientific processes. Although many times, people are interested in working on one portion of a project more than another—capturing the images for a community map or stitching the images after they have been collected—the Public Lab process calls for a reimagining of power inherent in many citizen science projects (Lakshminarayanan, 2007). Involving people in the entire data lifecycle means that individuals don't just enter a project at the stage of collecting data for a preconceived research project. Beyond those initial activities, they are empowered to become active and involved collaborators at every step of the process from problem identification and engaging with hardware and software tool creation (as collaborators) to further data collection, analysis and localized instances of advocacy. Emphasizing the people and knowledge production involved in the process, rather than just the tools, technology and data created, counters issues of power and ownership that are prevalent in science and mapping. An open, cooperative community encourages cross-pollination from a wide spectrum of expertise from academic to localized (Frickel, 2011), and reflects a greater societal desire for inclusive, transparent, civic collaboration and engagement rather than isolated, black boxed (Latour, 1987) research.

In this article, we review current practices in citizen science and "crowdsourcing", summarize the progression of the Public Lab community from one focused on participatory geographic data collection to an environmental monitoring network, and through case studies and examples, examine some of the challenges the project faces in the construction of alternative models of expertise.

Citizen Science & Crowdsourcing

Public Lab's *Grassroots Mapping* project draws on both grassroots, citizen science and counter-cartographic traditions, in particular neogeography, participatory GIS (PGIS) and critical GIS concepts. These traditions have not been without their pitfalls and they have often had to grapple with digital divide, expertise and access. The primary contribution of tools like those created by Public Lab is, as Elwood and Lesczynski (2012) have suggested, the advancement of new ways of knowing. Public Lab tools are rooted in the participatory processes of PGIS and are designed to enable non-experts to participate in the creation of credible data in the same digital formats as traditional and institutional practitioners of geography, and in this case, remote sensing and environmental science (Chambers, 2006; Goodchild, 2009). While increased civic participation in scientific investigation is a stated goal of many citizen science initiatives, which cite "improved public awareness" of scientific research and increased acceptance and adoption of its findings as motivations for engaging with the public (Munger, 2009), this is civic participation intended to benefit science and professional scientists, not the citizen. Many such efforts engage volunteers solely in data collection or even data entry, and make use of lay contributions primarily as a form of low-validity data which must be triangulated, filtered, and curated by experts (Silvertown, 2009; Grey, 2012). In environmental citizen science efforts, strictly prescriptive or *black-boxed* data collection methodologies may disregard local participants' deeper understanding of an ecology with which they, as residents with daily exposure to the local environmental issues in question, may be intimately familiar (Latour, 1989; Goodchild, 2009). Many such data collection or data entry initiatives only accept data which has been redundantly entered in duplicate or triplicate (Fry, 2009). Few engage volunteers or lay contributors as peers who receive co-author credit or are able to participate in later stages of research such as data interpretation and analysis. Despite claims about the "wisdom of crowds" (Surowieki, 2004), projects which make use of *crowdsourcing* treat participants as part of an engineered system rather than active collaborators in research (Schawinski, 2008; Munger, 2009; Benkler, 2006).

Though Public Lab's work drew upon PGIS practices, the balloon and kite mapping techniques it developed were distinct from earlier work in several ways. With its focus on aerial photographic mapping, it represented a break from the primarily Cartesian, or vector-based representations of space, in favor of raster photographic imagery, as in remote sensing. While many PGIS techniques make use of drawn maps (sketch mapping), digital maps, or even natural materials, as in ground mapping (Rambaldi et al. 2006), Grassroots Mapping has sought to challenge the idea that raster mapping is a more objective way to describe a geography. The ability of individuals and especially under-resourced groups to make raster maps has for the most part been limited by the expense of capturing satellite imagery or of an overflight in an aircraft. While the rise of free online satellite imagery services like Google Maps has made access to imagery commonplace, the relatively low resolution and lack of control over *when* images are collected has limited the degree to which such maps may be used to capture specific time-situated narratives. While it is impressive that one can view 1 meter imagery (where each pixel represents 1 square meter of the earth's surface) of many urban areas, many parts of the world are represented only in out-of-date imagery at poorer resolutions, where individual roads and buildings are hard to see, let alone people. Balloon and kite mapping have allowed practitioners to choose not only a place to describe through photographs, but a moment in time to capture events unfolding, such as a protest or a chemical spill. This kind of map making attempts to situate aerial photographic mapping as a narrative or journalistic tool by making it possible to "frame a shot" in time and space, while using a medium formerly the exclusive domain of industry and government. That these techniques involve collaboratively developed hardware -- from ways to stabilize and suspend a camera to techniques for rapidly winding and unwinding string or triggering photographs -- also distinguishes the Grassroots Mapping project from prior PGIS techniques. As the Public Lab community has grown, the approach of using do-it-yourself hardware and open source software have additionally been applied to new problems such as chemical identification and plant health analysis.

Public Lab's organizers advocate for a transformative citizen science (Blair et al., 2013), or what Haklay (2012) calls "extreme citizen science." This is a citizen science where non-professional scientists are engaged in all steps of the process from question formation, to data collection and analysis of results. Contributors to Public Lab don't see their work as simply conventional science which happens to be performed by members of the public, but a science whose very meaning is transformed by its practitioners, whose perspective from outside the science establishment informs their work, and who see science not as an end in itself, but as a means to investigate and interrogate what concerns them in their immediate environment.

In contrast, most citizen science projects today see contributors as an abundant and free resource -- what Dave Munger of ResearchBlogging.com refers to as "the most powerful computational resource on the planet: the human brain". This attitude mirrors the business practice known as "crowdsourcing" -- the engagement of the public through an open call to accomplish work, often on a volunteer basis (Estellés-Arolas, 2012; Hirth et al., 2011) -- and many citizen science initiatives are quick to adopt its attitude towards the "harnessing" of public participation. Though some projects cite contributors as having made discoveries ("Algorithm discovery by protein folding game players", Khatib et al, 2011), few give participants credit as authors. A notable exception is the FoldIt project (http://fold.it), which engages gamers in exploring solutions to protein engineering research questions -- and whose creators have regularly cited "Foldit players" as co-authors in articles. Still, the prevailing attitude is that *scientists* collect the data from the public and drive the later stages of science practice, including analysis and interpretation -- and this attitude towards expertise is particularly strong in the health and environmental sciences (Murphy, 2004; Allen, 2001; Fortun, 2005).

In response to these trends, we propose the alternative term, "*crowdharvesting*" as a means to critique the framing of participants as a resource rather than as full collaborators, and the disparity in power over the framing, direction and interpretation of the research. At worst, "Human Intelligence Task" management systems, such as Amazon Mechanical Turk, situate participants in crowdsourcing as faceless components of computing infrastructure. These systems create an "application programming interface" or API for automated task scheduling and management of "workers" -- designed by software engineers, they sport the vocabulary of networked computer systems, rather than that of collaborative agreements or labor relations (Amazon Mechanical Turk website, 2012; Fort et al., 2011; Horton, 2010). Less dehumanizing, but still patronizing is the "gamification" trend in crowdsourcing science. Many initiatives treat volunteers as essentially uninterested or incapable of understanding broader science goals or outcomes. The "Be a Martian" program by NASA's Jet Propulsion Laboratory and Microsoft (http://beamartian.jpl.nasa.gov) invites volunteers to pretend to become a citizen of Mars; colorful and childlike graphics present a fake "control panel" suggesting perhaps that contributors "play make believe" as they help NASA to classify images of craters (Viotti et al., 2010). The site extends no invitation to participants to take part in or even follow later stages of analysis, offering instead the opportunity to "earn points by tagging photos" or "send a postcard". Such tactics imply a "make it fun and they'll do the work for you" attitude which treats contributors as parts of lab infrastructure, emphasizes the boundary between researcher and lay participant, and demeans those outside of traditional research institutions (Deterding et al., 2011; Prestopnik and Crowston, 2012). For this reason, members of the Public Lab community draw distinctions between conventional "crowdsourcing" and truly participatory alternatives.

Open Data, OpenStreetMap, and Ownership

A number of recent community efforts to collaboratively produce open map data have broken with the aforementioned models of citizen science and crowdsourcing by placing community needs and decision-making processes at the center of data collection efforts -- broadly sharing authority over, for example, editorial and cartographic decisions over the construction of maps. Chief among them is OpenStreetMap (OSM), a worldwide community of over 1,000,000 contributors to a comprehensive and open source map database that began in the United Kingdom in 2004 as an attempt to provide a free and open alternative to the government-controlled Ordnance Survey maps (Chilton, 2009). While drawing on many of the same themes -- participation by non-professionals or non-experts in geographic data collection -- many in the neogeographic movement came not from the PGIS movement, which is not widely known or cited in the former, but from the free and open source software (FOSS) movement (Goodchild, 2009). Founded by grassroots mapmakers and proponents of open data who believed that a communal effort could outstrip centralized, commercial vendors, the project has been hailed as a "Wikipedia of maps" which has been cited as comparable in accuracy and recency to commercially available road maps -- and has been adopted by companies such as MapQuest and Apple over commercial alternatives (Haklay, 2008; Ciepłuch et al., 2010).

An important structural difference between open source collaborations and top-down citizen science efforts is that the former are directed by communities of participants; they are recruited not to help "experts" achieve a goal, but as valued contributors towards a set of shared goals which they may participate in framing (O'Mahony, 2007). This results in a strong sense of ownership as community members direct data collection, from the observation and entry stages to eventual processing and publication. Authorship is clearly cited in any use of the OpenStreetMap dataset, and failure to do so result in public outcry (Thier, 2012). Yet the output data is similar enough that those seeking to make use of it -- whether as basic map tiles or in routing or analysis -- may "switch over" with relative ease, adding to the credibility and perceived value of the communal alternatives (Turner, 2012; Hardy, 2012).

Grassroots Mapping

Much like OpenStreetMap (OSM), the Grassroots Mapping project, a precursor to Public Lab, began as an effort to provide an alternative to a tightly controlled source of data, in this case Google Maps. Instead of focusing on GPS-based vector data as OSM did, participants began collaborating to produce open source aerial photography and eventually projected aerial raster maps. Also like OSM, the Grassroots Mapping community worked to ensure that mappers could produce the same formats of data -- geoTIFFs and web-viewable TMS, or *tiled map services* -- as their commercial counterparts. The use of these formats was intended to bolster credibility for locally produced map data and to smooth integration with that of formal, authoritative providers such as NOAA, NASA, and commercial vendors such as Google Maps. However, the interests and emphases of the Grassroots Mapping community quickly expanded for several reasons (Warren, 2010; Chilton, 2009).

The mechanics of Grassroots Mapping's balloon mapping approach, which has been adopted and expanded upon by Public Lab community members, involves attaching inexpensive digital cameras to tethered balloons and kites at altitudes up to 4,000 feet, a technique that has been optimized for a very different set of constraints and goals than Google or its satellite imagery vendors. Rather than spending millions of dollars on high-end imaging sensors and orbital satellite platforms to achieve the best price-per-resolution for imagery of the entire globe, Grassroots Mappers have focused on producing hyper-local maps of small communities, sites of pollution or territorial claims. While covering at most a few square kilometers, these "balloon maps" tend to have much higher spatial resolution than commercial or government satellite imagery: typically 2-7cm resolution as opposed to 0.5-3m resolution for commercial imagery. Such imagery is detailed enough to clearly depict individual plants and animals, while imagery found on Google Maps is usually not sufficient to show individual people. Balloon maps also tend to have richer colors, and Grassroots Mappers have re-mapped sites multiple times to assess change over time, increasing temporal resolution (Long, 2012; Warren, 2010).

Balloon mapping also tends to be more narrative, both in what it depicts and in mappers' reasons for collecting data. Mappers talk about how the ability to make "our own 'satellite' imagery" puts them "in a position of power" -- clearly casting balloon mapping as a counter-cartographic practice rather than simply a well-constrained technology (Valuch, 2011; Burdick, 2011). Underscoring the need for independent coverage of controversial events, Elizabeth Wolf (2011), working with the nonprofit transparency group Ciudadano Inteligente in Santiago, Chile described how such documentation allowed demonstrators to dispute the mass media's attempts to cast their protests as violent:

> *We wanted to demonstrate and strengthen the perspective of viewing protests from the citizen's point of view, in order to broadcast to the world the majority, rather than the minority of the behavior of the attendees [of] these events. We wanted to show a grassroots movement from a truly grassroots perspective.*

Finally, Grassroots Mappers began to organize around collecting and archiving data of specific events which they felt were under-represented by traditional science. This became a high priority for many in the community as the Deepwater Horizon oil spill unfolded in the Gulf of Mexico in late April and early May 2010. Organizing in a matter of days, and with the cooperation and extensive support of members of the Louisiana Bucket Brigade and other interested New Orleans and Gulf Coast residents, Grassroots Mappers began leading almost daily trips to use balloons and kites to map coastal areas. While not attempting to produce imagery of the entire coastline, which stretches several thousand miles from Louisiana to Florida, the mappers focused on acquiring high resolution imagery of specific sites, with the goal of producing before and after maps (Warren, 2010; Long, 2011).

The Gulf project brought into focus several new considerations in the practice of grassroots mapping. It forced rapid adaptation of new technical approaches to new conditions and purposes. Windy shorelines cemented the role of kites as a working alternative to balloons, and mappers experimented with launching from or even towing kites from boats to map hard-to-reach areas in the coastal wetlands. In response to the immediate need to document the effects of the spill, grassroots mappers -- both on-site and around the country -- developed new ways of stabilizing and protecting cameras, automatically triggering photos, or sorting and stitching large numbers of aerial photographs into maps. Contributors to the effort ranged from fisherpeople with deep understanding of local ecologies and territory, to community organizers working to mobilize and coordinate volunteers and local residents, to software developers and electronics enthusiasts, to traditional researchers interested in coastal wetlands data. While this growing community struggled to find common language and even channels of communication, participants eschewed centralized control in favor of an "everyone pitch in" attitude and an agreement both that all data be released into the public domain, and all technology developed be shared openly with the community and the broader public.

The particulars of the Deepwater Horizon disaster highlighted the ability of independent mappers to access and document unfolding events at a level of detail beyond the reach of conventional techniques. The resolution and clarity of oil spill imagery collected by grassroots mappers greatly exceeded that of NOAA or the Coast Guard, and it provided detailed, hard-to-find imagery for journalists covering the spill (Bilton, 2010). An increasing media blackout denied journalists access to spill-affected sites through the imposition of an FAA flight restriction preventing flights below 3,000 ft in the heavily oiled Breton Sound, and incidents of officials and Deepwater Horizon representatives chasing journalists off of public beaches added to the already opaque cleanup efforts to create a real shortage of information regarding the spill (Peters, 2010). This placed mappers in the role of journalists -- and advocates of a different perspective of the effects of the disaster (Warren, 2010; Long, 2011).

A Public Laboratory

The Public Lab community was founded in the fall of 2010 by seven members of the Grassroots Mapping project who sought to create a broader infrastructure and community for the development of rigorous grassroots science and technology which serves the public. Drawing on the idea of "civic science" as proposed by anthropologists of science Kim and Mike Fortun -- a science "that questions the state of things, rather than a science that simply serves the state" (2005), and inspired by the robust technologies developed by open source software communities, Public Lab's founders proposed an open research community dedicated to developing a collection of new tools for investigating local environmental issues. Released under open source licenses, these tools had already begun to develop in response to environmental monitoring needs during the Deepwater Horizon oil disaster, and included a means to take near-infrared photos for assessing plant health, a thermal imaging technique for identifying thermal pollution or poor insulation, and a simple spectrometer intended to characterize chemical pollutants (Dosemagen et al., 2011).

The community which has come together to form Public Lab differs from its earlier incarnation as Grassroots Mapping in several regards. Sharing of techniques, tools, advice and data is more explicit, backed as it is with formal open source licenses such as the GNU General Public License, Creative Commons Attribution ShareAlike License, and CERN Open Hardware License for software, content, and hardware designs, respectively. Public Lab researchers have also begun to investigate and monitor new sites of environmental concern and environmental health problems, in an attempt to provide an alternative to the systematic lack of transparency and tendency of “official science” to use expert-oriented language and data analysis and publication which is inaccessible or illegible to key local actors.

In environmental justice work, the kind of transparency embraced by Public Lab's organizers presents some risks -- what if a corporation or individual with different motivations made use of, for example, balloon mapping techniques to further violate the privacy of a vulnerable community, or even to identify and extract minerals deposits to the detriment of local ecologies and human health? The temptation to restrict the use of technical contributions is high, but Public Lab's founders offer three arguments against such restrictions. First, that actors with power and money -- like the state, or corporations -- already have expensive technoscientific resources at their disposal due to their position at the center of power structures (Maron, 2009). Second, that a culture of transparency and critical discourse is a better mechanism than legal control for ensuring the ethical use of technologies (i.e. the weight of public opinion). Thirdly, that unrestricted access promotes wider use by the public, and levels the playing field for disenfranchised and underprivileged users -- and even encourages adaptation of technology to new problems which could not have been anticipated by a more curated group of participants (Maron, 2009). Still, where the privacy of a fenceline community, or their exposure to legal risks or coercion is at stake, Public Lab organizers are careful about the use of public channels.

Who are Public Lab Contributors?

Public Lab occupies a middle ground between emerging technology-centric groups such as Safecast and Smart Citizen projects, and environmental justice groups who have worked closely with affected communities for decades. Examples of both of these groups have begun to participate in the Public Lab network, both through formal partnerships such as the Gulf Monitoring Consortium and by using the Public Lab website and discussion lists as a platform to promote and recruit participants, as the Photosynq project from the Kramer Lab at Michigan State University has done. Public Lab was named with the intent to create a laboratory that exists in -- and engages with -- the public; a virtual laboratory without walls, and a space for investigation outside the ivory tower or the industry lab. In that light, the Public Lab staff has sought to cultivate a distributed research network, rather than developing an in-house research team; the Public Lab website invites members to embark on their own projects and to start local meet-up groups to pursue locally relevant environmental science and health issues.

In envisioning the Public Lab, its founders also drew on the concept of "recursive publics" proposed by Chris Kelty (2008), anthropologist of science and technology. In "Two Bits," Kelty describes how open-source software communities are brought together by working on, improving, refining and versioning the technology which connects them: software code. Unlike a representative democracy where citizens vote periodically for representatives who work on their behalf to shape their society with laws, open source software projects use collaborative coding tools to enable contributors to actively reshape their own community's infrastructure by collaborating on development, generating offshoots or forks of existing work, and proposing and implementing working code which can refigure the structure of participation.

In practice, attempts to build close collaborations and new kinds of partnerships between technical and local monitoring groups have been slow to overcome cultural divisions, with online discussions tending to focus on technology issues or generalized data collection strategies while local, in-person meetups have dealt more closely with pollution events and specific environmental justice issues. These cultural differences mirror the gap between formal expert research communities and the concerns and perspectives of local residents, and likely reflect the persistence of such frames despite attempts by Public Lab organizers to challenge them (Fisher, 2000). Challenges remain for the community in encouraging local activist groups -- many with valid concerns about the potential repercussions of public disclosure of their ongoing monitoring work -- to safely leverage the expertise and interest of technically skilled members of the Public Lab community. Likewise, there is a persistent need to push this latter group to frame technology development around specific real-world problems, and to draw upon the deep experience of those who investigate and experience pollution firsthand. When this succeeds, there is potential for local perspectives and expertise to play an active role in public policy and planning. Community organizer and Public Lab community member Eymund Diegel argues that this is already happening in the Gowanus Canal Conservancy's data collection work:

> *We have the ability as local residents to contribute specialized local knowledge to the planning and decision making process, and Public Lab gives me the tools to reconnect the State and its agencies of change to Grassroots local insights - which makes for better solutions through better fact finding.*

Notably, in cases such as the Gowanus, the ubiquity of some types of contamination, specifically from oil and gas, presents an opportunity to break down these divisions further; in many urban areas such as the Gowanus Canal, contaminants such as raw sewage and poly-aromatic hydrocarbons (PAHs) affect diverse communities which include members of both of the above groups (Pearsall, 2013).

Public Lab seeks to invite contributors to propose new research questions, form new informal working groups, and explore new solutions to problems -- actively pursuing alternative modes of science practice and sharing both process and outcomes openly. University students, traditional scientific experts, artists, designers, activists, educators, and concerned residents can all be found on Public Lab's various discussion lists, and are welcomed by organizers to participate, on the condition that they share their work under the same open source license used by other Public Lab contributors. An example of this is the work of Leif Percifield, a New York-based technologist who has contributed to the "thermal fishing" project, which is attempting to develop affordable thermal pollution sensors for waterways. Percifield argues that in open hardware projects, the "expansion of tools and incorporation of people from a huge variety of fields and backgrounds is essential to how tools are designed and then created."

As a community which includes formal and informal experts, Public Lab's open publication and discussion model attempts to create opportunities for the exchange of information across traditional role and expertise boundaries. Many contributors without formal expertise (e.g. outside of accredited science institutions) have begun to see the Public Lab as a space to engage formal experts and to leverage experts' understanding of traditional science practice, or to compare grassroots science processes and data to their formal equivalents. Alternatively, some contributors seek help in legitimizing grassroots data by, as one put it, processing data "in a manner that maintains industry standards as close as possible" (Gradguy, 2011).

Likewise, formal experts participating in the Public Lab network see opportunities to apply their knowledge and abilities to "real" problems, to promote "expert" scientific ideas and approaches to science production, to engage volunteers in the collection and production of data, to better understand "real world" problems, and even to adopt cheaper and more customizable instrumentation. Some are also motivated by what they see as an opportunity to educate the public in their respective areas of expertise. Many are excited about the opportunity to challenge the status quo in environmental science, and are well acquainted with current structural problems in collecting and leveraging environmental data. Scott Eustis, a Public Lab organizer and coastal wetlands specialist with the Gulf Restoration Network, expresses frustration with contemporary monitoring technology:

> *These devices ... are cost-prohibitive for non-profits, and shape official government response monitoring practices in ways that retard effective sampling (2012).*

Though this exchange between formal expert and informal contributors is promising in that it presents an opportunity to pool grassroots and scientific expertise in the exploration of an alternative science practice, Eustis's concern highlights a central challenge of this effort -- that the existing means of collecting, analyzing, and acting upon environmental data is often structurally unable to recognize, incorporate, or address the concerns and perspectives of local, grassroots communities. Eustis's comment also points out the possibility that existing sensing methodologies may not produce "good science" in the first place (Allen, 2003; Frickel, 2011; Fisher, 2000; Ottinger, 2010).

Civic Science at the Gowanus Canal

One example of the environmental issues which local chapters of Public Lab have begun to explore is the Gowanus Canal Superfund site in Brooklyn, New York, where the New York chapter of Public Lab has begun an ongoing periodic monitoring campaign in partnership with local environmental advocacy group the Gowanus Canal Conservancy (GCC). Designated a Superfund cleanup site by the EPA in 2010 due to pollution from decades of coal tar accumulation in canal sediments, and suffering from 300 million gallons of untreated sewage which are released into the canal yearly, local activists have adapted and improved many of the techniques developed for monitoring the effects of oil contamination in the Gulf of Mexico. A local balloon mapping group, which has named itself the “Gowanus Low Altitude Mappers,” or GLAM, describes its activities on their Public Lab wiki page:

> *The data [we’ve collected] documents patterns/concentrations of vegetation or possible contaminants, monitors the stormwater retention design interventions that the GCC is installing along the canal edge, and reveals unknown or unidentified pipes or sources of groundwater entering the canal. In the long-term, this inquiry effort seeks to address the 300M gallons of untreated sewage that will continue entering the canal yearly even after the EPA finishes their Superfund clean-up of the toxic sediments at the bottom of the canal.*

GLAM has been a key adopter of an offshoot of the basic balloon mapping technology -- near-infrared photography. As activists, residents, and wetlands researchers collaborated to document the extent of damage from the Deepwater Horizon oil spill, they found that as weeks dragged into months after the spill, concretely identifying oil became more difficult. Were "dark brown" areas of maps and photos actually oil, or more importantly, could such facts be established with certainty and recognized as credible evidence by traditional scientists -- or in legal struggles (Harada, 2010; Harada et al., 2011; Judd, 2011)? Drawing upon academic and industry remote sensing techniques, and with the input of several experts in remote sensing and coastal geomorphology, Public Lab researchers began to explore both infrared and ultraviolet photography as a means to identify wetlands health and loss (Harada and Griffith, 2011; Warren and Griffith, 2011; Warren and Craig, 2010; Warren, 2011a).

In August 2011, GLAM successfully photographed much of the upper Gowanus using mylar balloons and a dual-camera rig, designed to take simultaneous infrared and visible-light photographs. The photographs were published on the Public Lab mailing list and website, and an initial test image was prepared, where image pairs were composited together to search for signs of photosynthetic activity in the canal, in a “homebrew” rendition of Normalized Difference Vegetation Index, a remote sensing technique often used with imagery from the LANDSAT project. The test image revealed a distinct plume -- a mark of a potential inflow into the canal (Barry, 2011). Eymund Diegel and other members of GLAM returned to the site of the inflow at low tide and discovered a metal panel covering the source, which led from the site of a future Whole Foods. Speaking to a reporter from the blog TechPresident, Diegel related the ability to collect such data as key in the production of, in the words of the reporter, "credible concerns backed by hard evidence" (Judd, 2011). He also voiced concerns about the attempt to obscure the stream: "Someone was trying to conceal some kind of outflow, I don't know why," Diegel says. "It was a natural outflow that collects water from Park Slope, and there's a stream running across the Whole Foods site. Because it was a constant water flow, someone may have connected some industrial flow to it and been dumping paint or whatever else . . . . But why else would you conceal an outflow?"

While the application of this technique demonstrates an affordable adaptation of expert technology, the interpretation of the resulting data has posed a challenge for members of GLAM. Diegel points out that other historic underground streams did not produce similar plumes; "We're still trying to understand the infrared imagery. The reason why it's still problematic is that in theory the infrared should be showing up a flow of two other spots... but it wasn't." Ultimately, however, the discovery of the inflow proved to be useful in another way -- an EPA commissioned survey of the canal had apparently failed to detect it, making it the second inflow which GLAM has identified but which the EPA missed (Barry, 2011b).

With balloon mapping, Diegel has been able to create bridges between the community around the Gowanus Canal Superfund site and authorities responsible for cleanup. "The high resolution of the balloon and kite pictures, coupled with my interest in historical maps of the Canal have allowed us to use Grassroots Mapping images as credible evidence of historic streams that will affect decisions about how the Superfund cleanup program will have to proceed," he said. Interpretation of data and the production of credible evidence, however, has continued to be a central challenge for Public Lab community members. Another, much larger plume was photographed from a balloon in Newton Creek at the north end of Brooklyn some weeks after the infrared mapping, by GLAM members working from a boat provided by Hudson Riverkeeper (Barry, 2011b). Eymund Diegel was quick to chip in:

> *That whitish discoloration in the water is coming from a lot owned by Brooklyn Union Gas Company, Block 2837, Lot 1, at 430 Maspeth Avenue. The building in the photograph is next to where Empire Transit Mix Co. parks their cement mixing trucks* (Diegel, 2011b).

The site had a history of pollution infractions, he pointed out, quoting the Hudson Riverkeeper website:

> *In 2002, Riverkeeper discovered that Empire Transit Mix, a concrete company, was illegally discharging its liquid cement wastewater into Newtown Creek* (Diegel, 2011b)

...and a 2005 news release by the EPA:

> *In May 2001, an EPA inspector was conducting a routine inspection of a nearby facility when he observed a significant discharge of grey-colored liquid from the Empire facility, into Newtown Creek. Following these observations, EPA and the FBI set up surveillance of the facility and subsequently observed numerous discharges. EPA sampled the discharge and found that it had a pH of 12, making it highly caustic and adding to the already serious pollution problems in Newtown Creek. The sampling allowed EPA to determine that the discharges were concrete slurry being discharged through a hole in the retaining wall of the Empire facility* (Diegel, 2011b).

The potential observation of a repeat offense seemed compelling, and Diegel voiced his hopes that the monitoring mission would lead to a cessation of pollution: “Grassroots Mapping's 2011 photo of the continued discharges shows how aerial balloon and kite photography provides visual evidence that could lead to better water quality enforcement” (Diegel, 2011b). However, Diegel points out that while visual evidence is important, more information is needed, including more comprehensive water quality testing. By documenting these kinds of clues, individuals in turn begin to ask questions. Diegel points out that, “although we may misinterpret information that is collected, it still helps us get to the real issues that are at hand.”

What is clear to these local residents and activists is that the official understanding of problems at these two waterways is incomplete at best, and that the tools they are marshaling in order to tell a different story are inherently value-laden. The Newtown Creek episode is just one example of the challenges Public Lab researchers face in developing an alternative mode of environmental science investigation. While efforts to mobilize residents and other interested parties to visit and document local sites of concern has met with success, Public Lab organizers have had more trouble building inclusive, collaboration around later stages of interpretation, data stewardship, and advocacy.

Public Lab and Academia

For a community attempting to situate itself as an alternative mode of knowledge production, a key question is how an initiative like Public Lab engages with existing expert institutions such as university labs. Early attempts at partnerships took several forms; wetlands researchers from the Louisiana Universities Marine Consortium (LUMCON) have sought to make use of the affordable and high-resolution monitoring techniques developed by Public Lab members, as well as to engage members of the public as participants in their research on the extent of oil spill damage. Some initial work on projects related to thermal imaging and kite photography was conducted by graduate students from Parsons University and the Rhode Island School of Design, and on an individual basis, many contributors to Public Lab have "day jobs" as students, faculty, or staff at universities. In many cases, university programs see Public Lab as a framework for public engagement -- a bridge between academic study and real-world problems. For its part, the Public Lab staff has sought to form university partnerships as an opportunity to situate informal work alongside traditional forms of knowledge creation, as well as to make use of university facilities or recruit student contributors to work on Public Lab projects. Even publishing in academic journals such as ACME is a means to draw links between formal research and Public Lab's body of informal research.

Despite these attractions, a variety of challenges arise in forming such partnerships (Delborne et al, 2011). One is that many universities operate with restrictive intellectual property policies that must be navigated by existing Public Lab members as well as potential participants before, during and after a class or event is hosted at an institution. Some universities allow students to hold complete intellectual property rights over the work they create during their studies, while others assert that such rights are the property of the institution. In a community which uses "copyleft" licensing, which requires that derivative works be shared under the same open source license, this can present a problem in that if students are not the sole owners of their intellectual property, they cannot contribute such improvements without explicit consent from the university. Furthermore, many students outside of computer science related disciplines are unfamiliar with the both the requirements of open source licensing and the conventions for attribution, publication, and sharing which come with it. This has led to misunderstandings and frustration on a number of occasions when either students or instructors did not fully understand the copyleft provisions under which Public Lab tools are licensed, and neglected to attribute or properly license derivative works.

The failure to cite collaborations or to properly attribute works has been a particular source of frustration for community members; Public Lab members contribute to and refine balloon and kite mapping methods with the understanding that their work will be properly attributed, and that "downstream users" will contribute their own improvements in turn. Unfortunately, in several instances, university marketing departments, researchers or members of the media covering a university-hosted aerial mapping event have failed to attribute Public Lab work, mentioning only the institution or its students or faculty. The importance of attribution cannot be understated in maintaining ownership in an open source community, as this is the foundation of the collaborative development process that created these technologies -- but traditional institutions have proven to be inflexible and even indifferent to such demands. Art practice in particular can on occasion not only neglect attribution, but obscure the means of production, as artists may consider the ability of others to reproduce one’s work to be a threat to their intellectual property. Open source practitioners, in contrast, see such replication -- properly attributed -- as a proof that their work was accessible, well documented, and popular. Both issues -- attribution and intellectual property -- may result simply from unfamiliarity with the conventions and principles of the open source movement. But they can also be understood as symptoms of disregard for the contributions of the informal researchers that make up Public Lab, and in some cases as an instance of the boundary between researcher and subject (Delborne et al., 2011; Frickel, 2011).

A particular challenge when a Public Lab chapter is hosted at a university is that it can potentially isolate the activities of the chapter from the broader community, and exclude members of the public. If the majority of work occurs in classes or student meet-ups which are not public, the burden of documenting and sharing internal work with the rest of the community is high -- and even well-documented works can create barriers to participation if student work relies on exclusive access to university facilities. Whether intentionally or not, such arrangements run the risk of creating a dichotomy similar to that of traditional models of citizen science, where researchers direct projects and local community members are merely participants (Delborne et al., 2011; Wynne, 1996; Collins et al, 1998). Some staff members have observed that the prescribed timeframe and resultant letter grades of the semester system can be disruptive to longer-term open source environmental and environmental health research.

One way to address these difficulties can be to move students and researchers physically outside of university spaces to community centers, hacker spaces or other public spaces which may help to diffuse the formal/informal boundary. This may likewise present interesting opportunities for students to build alliances and collaborations which would not be possible in the cloistered environment of a classroom or university lab; relationships which may continue outside of academic life. Some of the most successful cases of academic collaboration have occurred when students take the open source ideas they are exposed to in class and apply them in extracurricular projects. Oscar Brett -- who was first introduced to aerial mapping in a class at Parsons -- used the technique in collaboration with other protesters to create the first grassroots aerial map of an Occupy Wall Street demonstration. Such cases offer encouraging evidence that Public Lab modes of production can create opportunities for disrupting traditional academic practice.

Still, it is not clear whether close engagement with academic institutions provides enough benefit to justify the various risks such partnerships carry: that such collaboration may be less open to the public, that informal contributions may be co-opted by formal researchers, and that university researchers may disrupt informal research by not considering themselves to be peers in the process. As mainstream science practice has increasingly distanced itself and its methods from the public (Fisher, 2000; Wynne, 1996), there may be more to gain by exploring institutionally independent means of knowledge production.

Expert and Domain-specific Language

The Public Lab's efforts to foster inclusive and open research has often been hampered by the complex and often illegible expert language of traditional science, in which jargon can obscure the open exchange of ideas for those without formal science training (Hoffman, 2011; Partridge, 1971; Allen, 1993). This is compounded by the tendency of Public Lab members to create their own domain-specific “insider” terminology. For example, some balloon mappers tend to use the term "mission" to describe a balloon mapping flight, a practice which has met with objections from those who consider the word militaristic and technocentric. Likewise, techniques adapted by Public Lab researchers from formal science practice have brought unfamiliar terms to the website and mailing list -- such as "hyperspectral", "assay", and "PAHs" or "polycyclic aromatic hydrocarbons", along with other technical but not science-specific language including "intervalometer", "photogrammetry" and "ferrules". These reflect both a growing level of expertise among highly active members, and a tendency to use language that implies membership in a community, but for a community which strives for accessibility and inclusivity, this tendency presents a particular challenge.

To diffuse such language barriers, whether due to imported terminology or the creation of insider language, Public Lab staff and organizers have chosen (or invented) project names and terminology which reflect the open source nature of our work. The "Thermal Flashlight" project's name offers clues as to its usage, which involves waving a colored flashlight around a room to measure and display the temperatures of different surfaces and objects. The naming is intended as a kind of “source code”, hinting at the tool's purpose and methodology and evoking familiar use patterns. Other projects, such as "grassroots mapping" were named to refer to the structure of participation -- making maps that highlight local knowledge and perspectives -- instead of the technologies (balloons and kits) employed.

Public Lab's founders hoped to reconfigure accessibility and ownership in environmental science, and discussions about jargon are an integral part of a community in which participants seek to design not only useful tools, but the structure of participation itself (Kelty, 2008).

Methodological Transparency

Drawing on the principles of the open source software community as well as the emerging open hardware community, Public Lab members use the PublicLab.org website to document the means of production for the tools they create, as part of the collaborative process. However, more often than in software projects, hardware designs and research methods exhibit greater divergence in practice, in part because such designs and methods are exchanged through textual, graphic, video, and in-person descriptions and demonstrations, rather than explicitly by means of source code. Regional variations have evolved in such details as the means of triggering cameras during balloon photography, or the preferred sample containers for spectral analysis. New York City mappers continue to use a programmable camera triggering system despite the widespread use of a simple rubber band trigger elsewhere -- making for fewer images to sort through and better battery life and longer flights. West coast mappers often use rubberized gloves instead of the leather work gloves which are the favorite of east coast mappers (rubber gloves make it easier to grip kite string when reeling it in, while leather gloves make it easier to let string out at a constant rate as the reel slides easily through one's hands).

Though they result in part from the more regionally centered research collaborations (exchange of methods at local meetings rather than online), they may also indicate the development of regional preferences where the use of a tool has been adapted to locally available materials or field conditions, including weather patterns and humidity. Other variations may not substantially affect data collection, but reflect local styles and conventions. Some of these variations can be understood as a kind of physical jargon -- indicators of group affinities, and of the development of expertise with techniques of growing complexity.

In *Science in Action,* Bruno Latour argues against 'black boxing' of technology (1987), since obscuring the inner workings of a technology and its history of development fails to invite users to consider how it was developed, who created it, and why. The methodological variation described above provides some evidence that Public Lab techniques have continued to evolve, and perhaps due to contributors' attempts to avoid such black boxing, retain enough "methodological transparency" that they continue to be reconfigured and adapted by their users. Still, some degree of abstraction can be a powerful way to render complex systems legible and accessible to new users. At Public Lab, organizers and tool developers must balance a certain amount of black boxing -- for example in developing case-specific interfaces for complex software techniques -- with their continued desire to invite refinement and change in techniques and designs.

Conclusion

The concept of a "civic science" centers on whom is served by such an alternative scientific practice (Fortun and Fortun, 2005). In seeking to transform the role of science in public life, we argue that transforming formal science practice is less critical than enabling the participation of informal or non-experts in that practice, and in science-based decision-making processes. While both the Public Lab research community and traditional institutions stand to gain from alliances and the free exchange of information, legitimacy by association is a poor substitute for the building of a truly credible alternative to traditional institutional science. Even the tendency to consult formal experts in the shaping of grassroots science investigation can be limiting, premised as it is on the assumption that the conventions and techniques of formal science are by default more authoritative (Delborne et al, 2011). Rather, developing long-term sustainability in a distributed open source science effort such as Public Lab depends on successful alliances with other communities of lay expertise -- from farmers and fisherpeople to activists and technology hackers. Public Lab represents an ongoing experiment in adapting practices from open source software communities, but its greatest strength lies in its diverse constituents ability to innovate past the limitations of traditional science, to question its assumptions, and to offer both a critique of and an alternative to the assumptions it makes.

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