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Re-calibrating DIY: Testing digital participation across dust sensors, fry pans and environmental pollution

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Abstract

An increasing number of low-cost and do-it-yourself (DIY) digital sensors for monitoring air quality are now in circulation. DIY technologies attempt to democratize environmental practices such as air quality sensing that might ordinarily be the domain of expert scientists. But in the process of setting up and using DIY sensors, citizens encounter just as many challenges for ensuring the accuracy of their devices and the validity of their data. In this article, we look specifically at the infrastructures and practices of DIY digital sensing. Through an analysis of urban sensing in London as an environmental media practice, we consider the specific techniques and challenges of calibrating DIY digital sensors for measuring air pollution to ensure the relative accuracy and validity of data. We ask, "How are DIY calibration practices expressive of particular political subjects and environmental relations—and not others?" "How might we *re-calibrate* DIY as a digital practice and political commitment through engagements with multiple genealogies and counter-genealogies of citizen-led inquiry?"

Keywords

Air pollution, calibration, citizen sensing, communities, digital materiality, digital sensors, DIY, environmental media, feminist technoscience, participation

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Introduction

An increasing number of low-cost digital sensor kits and devices for monitoring air quality are now in circulation. From “Air Quality Egg (n.d.)” to “AirCasting (n.d.)” and “Smart Citizen” (n.d.) to “Plume (n.d.),” these digital technologies are meant to enable do-it-yourself (DIY) approaches to environmental monitoring. DIY technologies attempt to democratize environmental practices such as air quality sensing that might ordinarily be the domain of expert scientists. But in the process of setting up and using DIY sensors, citizens encounter just as many challenges for ensuring the accuracy of their devices and the validity of their data. While plug-and-play sensors at first appear to democratize environmental data gathering, the process of situating digital sensors within environments begins to unfurl numerous concerns about just how far this democratization extends, as well as what the limits of DIY might be.

In this article, we discuss our attempts to test, set up, and use a range of DIY air quality sensors. In the context of developing citizen-sensing technologies for monitoring air pollution, we have experimented with off-the-shelf kits produced by startup enterprises and undertaken practices of assembling and making our own low-cost sensor kits. The question of how best to calibrate devices has emerged as a central and unavoidable undertaking. Sensors need to be adjusted to a standard reference monitor or measurement in order to ensure the data they generate are roughly comparable to “official data.” Yet this process is riddled with complexities and differing approaches, some of which are fervently fought over in communities that develop and use DIY technologies.

We zero in on this technical, infrastructural, banal, geeky, and contested zone in order to explore questions about whom or what DIY practices enroll. We ask, “How are the technical-material commitments of DIY calibration practiced, and what relations do they inform?” “How are DIY calibration practices expressive of particular versions of democratization that validate some political subjects and environmental relations—and not others?” “How might we *re-calibrate* DIY as a practice and political commitment through engagements with multiple genealogies and counter-genealogies of citizen-led inquiry?”

To address these questions, we first discuss several DIY air-monitoring technologies and calibration techniques that we tested. We analyze the distributed techniques required to calibrate devices and the collective infrastructures that arose to ensure the “validity” of sensor data. We discuss how these techniques exceeded any single device and pointed toward the ways in which digital sensors operate through extended relations as *environmental media*. Second, we discuss calibration in practice by working through two sites of air quality monitoring that we have engaged with in Southeast London, including an “Air Walk” hosted where sensor technologies were trialed, and an “Urban Sensing” installation of sensors. In these sites, we elaborate on the ways in which digital sensors are mobilized in order to engage with environmental problems, as another instantiation of environmental media.

While there is an emerging body of theoretical and practical research on DIY sensor hardware and data platforms, the processes for undertaking DIY calibration are less established as areas of inquiry. Our research engages in detail with one particular dust sensor in order to analyze the technoscientific configurations that DIY sensing mobilizes. Yet as we suggest here, the technical aspects of calibration are just one component of the many ways in which sensors undergo calibration. In this sense, we situate this research within a broader consideration of environmental media, which is especially attentive to the sites, relations, and processes through which digital media form and are sustained. We build on work in environmental media (cf. Fuller, 2005; Gabrys, 2011, 2016; Parks, 2007; Starosielski and Walker, 2016) both to understand social-ecological engagements with DIY sensor technologies and to consider how these technical relations and practices can be re-calibrated.

By looking specifically at the infrastructures and practices of DIY within which digital sensors are entangled, we consider the subjects, users, and makers who are variously enrolled and constituted through digital DIY practices. We discuss DIY practices for social-ecological engagement through two somewhat different communities, including a distributed and primarily online community of makers who develop and provide instructions for digital sensors, and urban community groups who are concerned about air pollution in Southeast London. These two communities take up and use DIY digital sensors in quite different ways. Calibration here occurs not just through a device or devices but also in relation to the expanded technical practices and relations across the different commitments of these communities—one to technical development and the other to environmental justice. Through describing calibrated sensors in use, we attempt to generate and articulate these expanded approaches to calibration that occur across technologies, practices, participants, entities, and environments.

Taking up topics of relevance to digital media theory and environmental media, we address how the digital- and practice-based entanglements of calibrating sensors reveal the extended relations that make DIY technologies available, workable, and deployable. We further draw on feminist technoscience and science and technology studies to address how citizen engagement and formations of expertise emerge through calibrating sensing kits, which raise new points of significance related to the politics of digital technologies. We offer a different perspective on both DIY and calibration by attending to how calibration connects practices of environmental concern, sensor manufacture, electrical engineering, algorithmic processing, community exchanges, and network connectivity. The use of DIY environmental sensors, we suggest, requires an attention not just to calibrating for accuracy and validity but also to re-calibrating the relations that are mobilized through these practices.

The promises and proliferations of DIY

It goes without saying that there has been an explosion of DIY projects and activities that have more or less coincided with the rise of social and participatory media. While multiple communities are contributing to digital media, there are also newfound developments in DIY electronics, DIY biology, DIY infrastructure, and even DIY satellites. Both digital media and science and technology studies have had long-standing engagements with DIY practices and technologies. These studies have included inquiries into DIY media making and DIY as a critical or tactical method (Broeckmann and Jaschko, 2001; Paulos, 2009; Raley, 2009; Sayers, 2018). Research has also focused on the exclusions and promises of DIY in hacklabs and hackathons, as well as the political economies of free labor that are propagated—and exploited—through these spaces and events worldwide

(Davies, 2017; Dunbar-Hester, 2017; Irani, 2015; Lodato and DiSalvo, 2016; Powell, 2016). This existing DIY research has provided important and often critical insights into maker culture, DIY techniques, and modes of sociality, as well as new approaches to making within academic research.

Related practice-based inquiries explore making and using DIY technologies such as environmental sensors alongside affected communities (DiSalvo et al., 2012; Kuznetsov et al., 2011). Similarly, expanded engagements with DIY in areas such as feminist health have been attentive to the ways in which citizen-led practices can have transformational political and practical effects (McNeil, 2010; Murphy, 2012). These projects often reach into fields that include environmental justice, health care, exposure and atmospheric science.

While on one hand the phenomenon of DIY and digital technologies might seem to be specific to newer developments in computation, on the other hand it also draws on and references earlier DIY developments from at least the 1960s onward that emphasize low-tech, democratic, and makerly engagements with technology. These makerly engagements included punk DIY, particularly its feminist projects such as Riot Grrrl and Ladyfest crafting genealogies that are based more on collective spaces for practice (Cvetkovich, 2012). In the United Kingdom, 1990s counter-genealogies of DIY often intersected with activist projects, from Earth First! to Do or Die (McKay, 1998). Punk zine publications such as Race Riot and Punk Planet often featured environmental justice topics. Intersecting with punk DIY were a number of other projects mixing technological utopianism and environmentalism through DIY practices, including the much-cited Whole Earth Catalog (Brand, 1971; Turner, 2006).

Related and contemporary practice-based work in this area works through the tactical opportunities of low-cost sensor projects, such as fitting homing pigeons with air quality sensors to map pollution in Southern California (Da Costa and Philip, 2008). Emerging electronics markets such as Akihabara in Tokyo have also been key to the growth of DIY sensing. For instance, the DIY radiation-counter Safecast was developed at the Tokyo Hackspace (Abe, 2014). At the same time, there are not just versions of DIY but also DIT (do-it-together) and DIWO (do-it-with-others; Furtherfield, n.d.), which propose that doing things should also present opportunities for collective engagement. There are often tensions between the differing modes of DIY practices, where some DIY practices are avowedly against the grain of normative approaches to technologies, economies, and practices, while other DIY practices re-inscribe the usual power dynamics that are prevalent within tech sectors.

DIY can be seen to be a particular manifestation of participation, where within the current set of participatory projects emphasis may be placed on having a voice, forming a collective, or registering political dissent. At the same time, DIY in many respects emphasizes the importance of *making* things yourself. It is through this makerly, hands-on engagement with digital technologies that a more intensive and capable form of participation is meant to emerge. Doing-it-yourself is not simply a process of following instructions, therefore, but is a process of *re-making* technological engagement. DIY technologies and practices present the possibility that through piecing together, assembling, and making technologies, some greater understanding or engagement will be achieved. Such DIY technological engagement is meant to facilitate alternative approaches to established practices such as environmental monitoring and engagement by challenging the power dynamics of who can take up technologies, through what means, and what types of evidence can be formed through these different arrangements.

The collective engagement formed through DIY, DIT, and DIWO practices are multiple and divergent. There are many "DIY communities," knitting together technical and political work in distinct ways, with different emphases on technical innovation or activist concerns. We set out to trouble who and what counts as a "community" in relation to DIY so as not to harden the category in relation to one set of practices (most visibly, the development of monitoring technologies) and to explore how community is a formation in process, calibrating and being calibrated. Consequently, our understanding of what constitutes DIY is expanded here to include multiple genealogies of DIY practice, including forms of activism and direct action.

Within this extended and diverse set of DIY practices, we take up DIY in our own research as a feminist technoscience practice. To some extent, we suggest that DIY has its own established genealogies within feminist science studies. From Donna Haraway's (1991) collective worldings and affirmative cyborg imaginaries to Lucy Suchman et al.'s (2002) co-operative prototyping, calls for participatory approaches to technology are expressed both as modes of intervention and as configurations of other possible feminist technoscientific futures. These are characterized by a politics of situated accountability, including concern for more-than-humans and environments, which frequently run counter to normative political-economic formations.

DIY environmental media, however, does not always neatly fit into the sites and imaginaries of feminist technoscientific practice. Although DIY has been taken up by what Eric Paulos (2009) has described as "[a] fringe group of individuals usually labeled 'hackers' or 'amateurs' or 'makers'" (p. 181), DIY kits and devices do not automatically challenge producer-consumer models of technology. Rather, they can re-inscribe normative technological relations and practices, such that the hacker, maker, or amateur becomes a unit for propagating modes of technological exclusion and exploitation (cf. Rosner and Fox, 2016). Re-calibration, as we develop the concept and practice here, is a way to rethink and rework the social, technical, and material relations that constitute practices of DIY air quality monitoring. We discuss these calibrations and re-calibrations through our practice-based and participatory research into citizen-led air quality monitoring.

DIY calibration

Citizen-sensing practices then emerge as entanglements of DIY culture, activism, tinkering, hobbyism, amateurism, and startup culture, as well as environmental concerns, distributed materialities, and more-than-human interactions. Following the promises of DIY sensing in blogs, tweets, links, and workshop adverts, it would seem that the process of building an air quality sensing kit should be low cost, achievable, and relatively easy (even "plug and play")—or at least it should be available in a kit form or as an "instructable." However, despite the intensity of discussions and proliferation of devices, there are surprisingly few projects that have emerged for the easy and effective mobile sensing of air quality (although see rawrdong, 2016). This research project did not set out to build monitoring technologies from scratch, but rather sought to study the extant set of technologies for undertaking environmental monitoring. Yet, as we quickly discovered, many of these technologies are still relatively unstable and in beta phase. Through making off-the-shelf kits and developing our own monitors, we engaged with the processes of researching devices, spending hours trawling through forums and comments, posting questions to e-lists, searching for specific upgrades and fixes, and shopping for sensors and peripherals online and in electronic markets.

Unlike analog air quality monitoring using filters or diffusion tubes, digital DIY devices do not entail sending data to a lab for processing by experts. Instead, DIY devices are intended to present and distribute real-time data that can be processed and shared through open and commercial web-based platforms. However, even if sensors are made operational and platforms are developed for displaying data, multiple other processes are needed in order to ensure sensor data are relatively accurate. Digital DIY sensors then necessitate that verification techniques and protocols be developed alongside monitoring technologies. The DIY process and attempt to democratize environmental monitoring and environmental data require not just that sensor devices be assembled and made operational but also that data in some way can be verified. It is within this space of verification that we noticed that the calibration of devices had become a topic of intensive discussion, practice, tinkering, contestation, and development for DIY environmental monitoring.

Calibration is intended to increase accuracy between sensors, the electronic systems that support them, and the environments in which they are situated. Sensors are uniquely produced during manufacturing and may require harmonizing across sensors. They can be sensitive to physical changes during shipping or installation such as shock and extreme temperatures. Sensor capacities can also change across time as they age. Calibration in DIY air quality monitoring is often addressed in forum discussions, projects, and workshops as the process by which outputs from sensors are compared against another sensors or sensing infrastructure and then adjusted after this comparison. Adjustments might include setting a base level or zero, adjusting the scale of the readings, applying a scaling factor, or adjusting the resolution of the readings. These adjustments can take place through hardware, for instance, by adding further resistance within an electrical circuit on the devices themselves; through hardware and software, by adjusting algorithms in the source code on microcontrollers; or through software and platforms, by adjusting algorithms in the source code for the platform where the data are displayed and analyzed.

Yet calibration, as we found, can also involve testing sensors in situ, where environments and types of pollutants can inform the calibration process, the wear and tear of environments on sensors can create more or less sensor drift during the use of sensors, and the need for adjustments might be ongoing rather than a single moment in time. This way of calibrating and re-calibrating sensors pointed toward the environments and relations that can become a key part of how DIY technologies function and the communities they bring together. We now turn to discuss these multiple ways of encountering and working through calibration through two air quality sensing projects in Southeast London, an “Air Walk” and an “Urban Sensing” participatory monitoring project.

Testing DIY kit for an Air Walk

As part of an initial test of DIY air quality sensors, we hosted an "Air Walk" in 2013 in Southeast London as part of a conference event (Gabrys, 2017a). Developed more as a "walking seminar" (Mol, n.d.) than as a public engagement event, the Air Walk was a way to trial and experiment with air quality sensors through encounters with air pollution in London. The walk set out to investigate the various ways in which air pollution might be monitored, assessed, and experienced, whether through digital, bodily, or other means, and in relation to possible emission sources. Air pollution is a major cause for concern in London, with nearly 9500 people dying prematurely each year in the capital due to exposure to poor air quality (Walton et al., 2015). The sensing of air pollution is bound up with particulate matter, public and environmental health, as well as technologies, regulations, protocols, and civic engagement.

In the context of the Air Walk, we assembled three prototype DIY monitors for walk participants to use as a practical exploration of DIY sensing, including off-the-shelf products, and those existing in instructional form on websites. The walk participants formed a temporary DIY community. These monitors were put together rapidly over a week, drawing hardware and source code ideas from forums and instructional sites. The DIY devices monitored levels of key air pollutants such as particulate matter 2.5, nitrogen dioxide, carbon dioxide, and volatile organic compounds (VOCs). We approached the prototyping through practice and as non-experts, engaging with building DIY devices for monitoring air quality. At the time, we were beginning to develop a familiarity with assembling air quality sensors and undertaking the calibration that these DIY devices require.

As we set about prototyping kits in our office located in a sociology department, we used multiple ad hoc approaches to get the devices working in a space not necessarily designed for the operations of a soldering iron. In assembling the digital sensor kits, we drew on a variety of advice from forums and software written for other sensing devices. The existence of libraries and examples developed by existing open software and hardware communities of digital sensing and air quality sensing means that there are a number of iteratively produced source codes that could (with some adjustment) be "useful."

The process of calibrating a sensing device is one of enfolding hardware, software, and environmental events, to develop a sort of DIY environmental media. This is an approach that pays close attention, through practice-based research, to the materiality of media environments that propel both the micro-performances of sensors and the affective actions of communities. In the practice of activating a sensor through running code, it is often necessary to undertake a process of toggling across hardware and software. A configuration of a sensor and board can produce numbers that look like sensor readings on a computer interface without even being powered. The calibration of data then becomes an iterative process of working through configurations of hardware and software.

Sensors are also greatly affected by environmental conditions, and it can be a lengthy process to work out the configuration of heat, power, and computation needed to activate the sensor. Calibration is an ongoing practice that is entangled with the process of generating a measurement. Both the sensor and the air being monitored are continuously changing and differ from location to location. The need for calibration to some extent defies any promise of universalism in networked sensing devices. It also demands that we challenge the universalisms of digital media as the sensor is always in process with its environment. Nevertheless, we continued to draw on and test DIY approaches to calibration that attempted to develop a standard practice and approach, even as they worked with and through ad hoc materials and situations.

Calibrating dust sensors with fry pans

One of the kits for our Air Walk used the Shinyei Model PPD42NS Dust Sensor supplied by Seeed Studio (n.d.). A small black box mounted on a plastic board, the dust sensor is designed to measure particulate matter levels and is responsive to particulates with a diameter of 1 µm or larger. Particulate matter is particularly harmful to human health and consists of a wide range of materials, from salt and silica to diesel, pollen, and carbon that can be coated with VOCs.

The Shinyei sensor recognizes small invisible particles in the air through a light scattering technique. In this process, a light beam is projected between two points, and as particles enter the sensor chamber, they reflect and diffract the light. Because particulate matter is not a homogeneous form, different particles will have different shapes and reflective surfaces will reflect light differently. In addition, the composition of particulate matter may change depending on differing exposures and locations. For instance, particulates near a rail station could have more black carbon particles reflecting the light beam, in comparison with a sensor nearer to construction sites where there are more silica or fibrous particles in the air. Calibration emerges in relation to these differing entities, where in many ways the sensor *experiences* the particulate matter (Gabrys, 2016). To some extent, calibration of sensing devices is also the process of working with a device to understand its modes of experiencing. The differing compositions of particulate matter mean that there is no accepted test object for calibrating DIY. While some sensor manufacturers and DIY makers might calibrate using gases or polystyrene balls (Austin et al., 2015), this process is understood to be very different to using the sensors in the field, where they will be effected by a plethora of experiencing entities, including weather, Wi-Fi and mobile signals, electricity, pollution itself, other gases or particles, and not to mention positioning and location (Holstius et al., 2014).

The Shinyei sensor became popular in open software and hardware DIY air-monitoring communities when programmer Chris Nafis developed source code for the sensor after testing its performance and developing a more standard approach to calibrating the device. The Shinyei sensor we used in the summer of 2013 had been customized by Grove to plug into the "Grove system," a standardized, modular set of electronic components designed to enable the user to plug sensors into a base shield. The Grove base shield is designed to plug directly onto a microcontroller, which removes the need for soldering, wiring, or working out resistances, enabling environmental monitoring "with minimal effort" (Seeed Studio (n.d.) wiki).

While we were assembling "Air Walk" sensor kits, we encountered the problem of calibration in relation to the Shinyei dust sensor. Whereas a commonplace understanding might be that a sensor can be calibrated in the factory and remains calibrated as might be the case with a temperature sensor or thermometer, sensors such as the Shinyei used for DIY air quality sensing require a more process-based approach to calibration. The sensor is not as enduring as a thermometer, and calibration needs to be repeated throughout the life of the sensor to account for drift and other external effects. Since they are sensitive to their milieus and require ongoing adjustments, digital sensors become more evident as environmental media through these processes of calibration.

Our initial engagements with calibration included reviewing Nafis' calibration comparison tests that he had named "The Fry pan Bacon test." Nafis, an employee of General Electric Research, became interested in local indoor and outdoor air quality after suffering from allergies and asthma. While also reviewing air quality data from the New York Department of Environmental Conservation, Nafis began to test various particle counters for monitoring air quality, and he logged the data to a free sensor data platform, Pachube (2011). One of his devices included a Shinyei sensor connected to an Arduino microcontroller. In an attempt to calibrate his Shinyei dust sensor device, Nafis used the factory calibration from the Shinyei spec sheet. This presented a mode of calibration for translating the Low Pulse Occupancy (LPO) reading of the sensor into a measure of particle concentration. LPO is a measurement of the opacity of the air that circulates through the Shinyei chamber. By converting LPO to particle concentration, local measurements could be compared to official monitoring, as well as air quality limits for pollution levels. While the manufacturers of the Shinyei provide a factory calibration method of the sensor within the spec sheet, this is based on the exposure of the sensor to cigarette smoke, which produces a specific set of particles that are typically very different to the particles of urban air pollution. However, Nafis digitized this calibration method by developing an algorithm to convert LPO readings from the Shinyei sensor to a measurement of particulate matter (Figure 1).

Because part of the calibration process of particulate matter monitors involves exposing sensors to concentrations of particulate matter, Nafis ran a series of tests to compare a mid-range air quality monitor, the Dylos DC1100, to his DIY devices that used the Shinyei PPD42N. To generate a source of particulates, Nafis (2012) then fried up some bacon:

> My previous experience showed that cooking puts a lot of particulates into the air. So for a quick test, I fried some bacon on the stove and logged the results from the two sensors.

The results of this test (Figure 2) showed a similar pattern between the Dylos and the Shinyei. This pattern was used to verify the calibration value that Nafis had translated into source code and executed on the Arduino microcontroller. He then made this source code available both on his website and on Github. The code and the calibration adjustment figure began to rapidly circulate on forum discussions, software libraries, instruction books, components suppliers' sites, and the wiki pages for the unofficial supplier of the Shinyei sensor, which was Seeed Studio. From Arduino instructions on how to use a dust sensor, to its implementation in commercial projects, the calibration was translated into Japanese, Korean, Cantonese, Italian, and Mandarin.

In a discussion of the performativity of the Linux kernel, Adrian Mackenzie (2005) notes that Linux is a performative and recursive process in which practices of

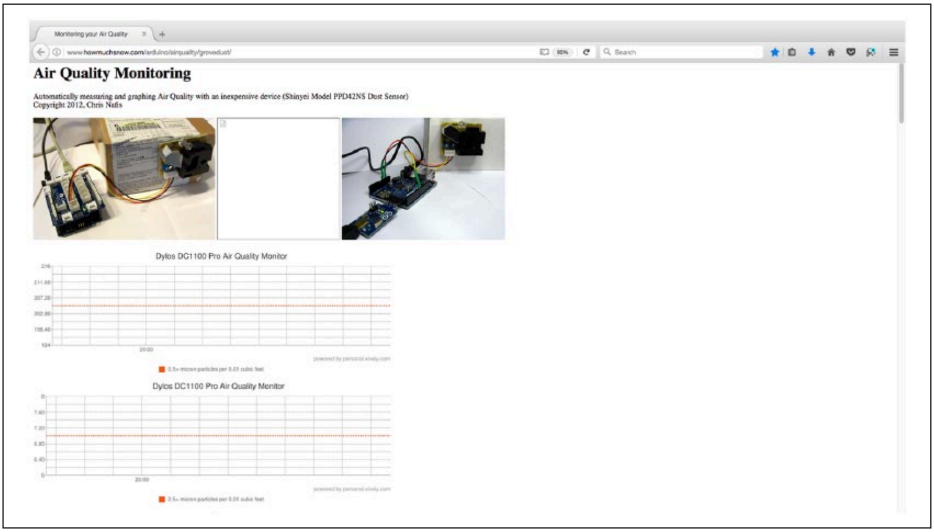

Figure 1. Documentation on digitizing Shinyei characteristics for calibration.
Chris Nafis, 2012. Screengrab.

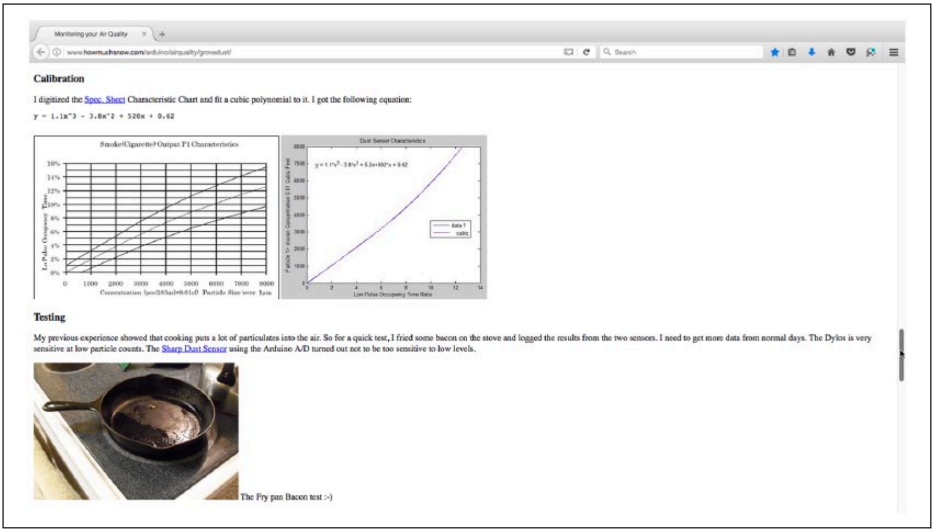

Figure 2. Documentation of fry-pan test of cooking bacon in order to generate particulates for measurement and calibration.
Chris Nafis, 2012. Screengrab.

describing and enacting what is described coalesce. The entanglement of the "The Fry pan Bacon test" and the Shinyei is also recursive, as the description of sensor calibrations and the enactments of calibration take hold and constitute how air quality monitoring is undertaken in the DIY realm. After the circulation of the Nafis source code, this calibration technique quickly became the standard process to undertake with the Shinyei sensor, with manufacturers even implementing the calibration. The digitization of the calibration opened up new markets for the Shinyei sensor and led to its distribution by suppliers for DIY sensors.

The cigarette calibration and fry-pan bacon test informed the use of the Shinyei in many subsequent projects, including the monitoring we have undertaken for our Air Walk. In preparation for the walk, we loaded part of the Nafis code onto an Arduino microcontroller and started polling data from the Shinyei sensor. However, what did the readings mean, and how did bacon particulates relate to the particulates in London air? As we were based in London where standards for particulate matter were written in micrograms per cubic meter and Nafis had calibrated the sensor for microgram concentration per 0.01 cubic feet, how could we adjust this reading to be in line with our local London Air Quality Network (LAQN)? Beyond these conversions of the materiality of air and the standards of measurement, the circulated code was not working in the way we assumed it might, and the readings we were generating with our DIY dust sensors produced much different measurements in comparison with our nearby regulatory monitors. Calibration, as part of the DIY process, was requiring not simply the adoption of a universal technique and measure but rather was opening up the many ways in which this was a contingent and mutable practice. This process points to the ways in which sensors and their environments are calibrated. Here, digital technology exceeds the singular sensor device and requires adjustments in relation to environments to function. Digital media thus become evident as environmental media, which are calibrated to and informed by their distinct milieus. Re-calibration further emerges here as a practice that requires reworking relations across devices, code, communities, environments, and particulate matter to be sensed.

From DIY calibration to DIY communities

From 2016 to 2017, we worked with communities in Southeast London to monitor air quality. In this area, we met residents and community organizations that were already using analog monitoring techniques—such as traffic counting and nitrogen-dioxide-sensing diffusion tubes—to produce evidence about local environmental problems and to petition authorities for changes to urban design. In collaboration with these communities and in response to their concerns about air pollution in London, we developed a particulate matter 2.5 monitor called the Dustbox to measure fine particles in the urban air (Figure 3).

Although they did not necessarily identify as “makers,” these Southeast London communities engaged deeply with DIY production. Some of these activities—such as maintaining a community garden and experimenting with roadway design—drew on lineages of direct action and DIY urbanism. Other practices were more explicitly connected to digital technologies, as community organizations raised money via crowd funding and explored how civic maker spaces might provide employment skills to local people. By addressing these different types of DIY communities, we resisted any foreclosure of this category, instead preferring to re-calibrate DIY and community as terms, concepts, and

Figure 3. Dustbox particulate matter 2.5 monitor.
Citizen Sense, 2016.

practices that present various technical-political entanglements emerging from multiple genealogies.

In this “Urban Sensing” investigation of air quality in London, we developed the Dustbox air quality monitor using the Shinyei PPD42NJ optical infrared dust sensor that we had previously tested through our Air Walk. Dustbox devices also included a micro-controller, Wi-Fi connectivity, and a miniature fan to ensure constant airflow and were housed in three-dimensional (3D) printed black ceramic housings designed to resemble particulates when viewed under an electron microscope. Dustbox devices collected real-time readings of particulate matter 2.5 that were piped to our open-access web platform, Airsift, that we developed to allow participants to undertake their own data analysis. Using this website, particulate matter data from the network of Dustbox devices situated in citizens’ homes and workplaces could be compared and analyzed alongside weather data, including temperature, humidity, wind speed and wind direction, and readings from the “official” monitoring infrastructure of the LAQN.

The Dustbox devices (and a logbook of instructions) were distributed in October 2016 following a public workshop and walk where attendees mapped and visited current and prospective monitoring sites. Dustbox monitors were also made available for free loan from the local library so that new participants could participate. During peak monitoring

Figure 4. Calibrating the Dustbox particulate matter 2.5 monitor at the Marylebone Road Atmospheric Observatory.
Citizen Sense, 2016.

activity, there were 21 active Dustboxes, and consistent monitoring took place at up to 18 sites over a period of 7 months. During the monitoring period, we organized three workshops to explore emerging patterns of particulate pollution shown in the Dustbox data and to discuss emissions sources and mitigating measures.

For the communities involved in our study, air quality issues were profoundly connected to urban land-use issues, particularly waves of densification (and gentrification), as large tracts of formerly industrial land were redeveloped into high-end housing. Dustbox monitors were intended to serve as "indicative" monitors that would allow environmental patterns to become evident. Participants sought to combine these indicative data with observations, analog sensing, and "official" monitoring data to materialize evidence for a range of initiatives. By calibrating monitors in relation to their environments and other monitoring standards and infrastructures, we continually tested and recalibrated the DIY practices that were also in the process of "tuning in" (Gabrys, 2012) to community concerns and to distinct ways of using data that inevitably exceeded a factory spec sheet.

Calibrating the Dustbox

In order to calibrate the Dustbox, we worked with two collaborating atmospheric scientists to develop a method for DIY Calibration. We began by running co-location tests at a West London monitoring site, the Marylebone Road Atmospheric Observatory (Figure 4). The co-location process involved running three Dustboxes alongside the "official" particulate matter 2.5 sensors at the Observatory to measure how aligned (or not) the

Dustboxes were with the regulatory monitors. With this approach, we developed an adjustment number based on the comparison of instruments' readings that we used to bring the Dustbox readings more in line with the Observatory readings. This process of calibration recognized the situatedness of the sensors, much more than so-called blind calibration, where sensors are calibrated in ways that are not responsive to the conditions and environments where they will be used. Unlike the bacon test or the cigarette-smoke factory calibration, here we were attempting to work with the London environments in which the Dustbox would be used.

Our approach to calibrating the Dustbox in this way was also informed by extensive experience of working with particulate matter monitors and testing multiple different techniques for calibration. With the Dustbox, we were tuning in to the specificities of the London air by developing and calibrating a device oriented toward the types of particulate matter found in the city. By choosing to calibrate by co-locating with the "official" regulatory monitors, we were also in some respects tuning in to the established scientific infrastructure that informs policy and legislative action on air quality. By developing this DIY calibration technique, we were also taking seriously the initiatives of the urban communities with whom we were working, where sensors might be more aligned with understanding London air, rather than particulates from a fry pan.

Calibrating and re-calibrating again expanded here to encompass environmental conditions, community initiatives, local air, regulatory infrastructures, adjustment values, and scientific practices that could be made usable as a DIY technique. In this sense, the Shinyei-based Dustboxes further operated as environmental media, both as distributed and environmentally informed devices and as digital technologies documenting and addressing environmental pollution. Calibration techniques were reworked and re-calibrated in this way to become more specific to the conditions that would be sensed—and to the possibilities for using sensor data.

Calibration as a relational practice

As DIY kits and platforms stabilize into global products, the process of participation can become marketed as simply buying a device, signing up to a platform, and collecting data. Calibration is a central issue here, as it concerns the validity and accuracy of devices and their data in particular environments. Calibration is a co-constitutive technical and political practice, where adjustments to devices according to cigarette smoke, frying bacon, or co-location techniques shape the ways in which the data collected can become mobilized for political change. Calibration contributes to the process of producing "just good enough" data (Gabrys et al., 2016), logging indicative environmental patterns that can organize Southeast London communities and enable engagements with regulators.

In DIY practices, the process through which a standard technique such as calibration comes to take hold is often undocumented or least not documented in one location. Instead its uptake is spread across forums and Github repositories, project documentation, blog posts, and occasionally in peer-reviewed papers. When we began working with sensors, we were learning about calibration processes, and for a long time, we had a working list on our whiteboard of aspects of setting up and using sensors that we were researching. Details of how best to calibrate DIY sensors were one of these key areas for research, and this focus was shared with many members of a loosely connected online DIY community and occasionally offline across geographically distributed sites.

Here, the term "DIY community" refers to more recognizable groups of "makers," including enthusiasts, amateurs, scientists, and researchers motivated by a shared interest in measuring air pollution. Numerous posts on DIY forums and discussions at conferences were taking place that covered the range of questions, from "What do I do with this reading?" to "What is this reading?" and "When is zero really zero?" Frustrations were aired, including queries about how to compare devices such as the Air Quality Egg to "official" regulatory monitors. The process of DIY calibration appeared to be messy and unresolved, and yet in search of a standard approach.

Processes of rewiring and adjusting sensors can also be made so that measurements can be translated, for example, by converting voltages into weights or light scattering into particle counts. These adjustments involve calibrating the sensor to bring it into line with another device that is held up as a standard, or a "gold standard," as is sometimes referred to by atmospheric scientists. However, because calibration can take place in many different parts of the sensor ensemble, any change to the sensor such as cleaning it, moving it, or changing its power supply could mean that it requires additional calibration. The atmospheric scientists with whom we collaborated to co-locate the Dustbox describe this process as the sensor becoming new again. On visiting a UK supplier of sensors, we witnessed hundreds of sensors undergoing calibration, stacked in racks with flashing red lights, an impressive and affective scene, yet as we learned through using the sensors, that this elaborate performance of calibration is only applicable to the sensor in that situation, on that day. On leaving the factory and traveling to new sites, the sensors, like the DIY sensors, would require re-calibration.

The shifting sites within DIY air quality monitoring might suggest that standards for practices such as calibration and adjustment are also flexible and emerging. One manual on atmospheric sensors suggests that the best way to (re)calibrate in the field is to bring a plastic bag of clean air from another location close by and expose the sensor to this (McDermott, 2004: 654). One of the sensor manufacturers recommended that we use a method that involves taking the monitors to a place without pollution to understand what its zero reading might be. Yet both of these methods are practically impossible within air quality monitoring. In attempts to calibrate the Shinyei, DIY practitioners have used a number of inventive approaches that span from creating test objects to co-locating devices. In another way, participants using the Dustbox would observe whether sensors were registering spikes in their data by exposing the device to cigarettes, lit matches, lawn mowers, and vacuuming. In addition, participants undertook comparisons between devices and the local official monitoring networks.

Despite these multiple methods and the contingency of calibration, we found that particular methods quickly became established as the authoritative approach. Within the air quality monitoring community, groups and individuals had differing motivations—some were primarily engaged in negotiating the technical challenges of building a monitoring device, while others also grappled with questions of how DIY data might be legitimately mobilized to address air pollution as a political problem. In the struggle to become recognized as a legitimate undertaking, online DIY communities argued for particular calibration and adjustment practices while decrying others. Calibration, and discussions of calibration, could then lead to outbursts on social media or in online forums over the best calibration techniques to employ, with DIY makers as well as scientists attempting to use low-cost devices entering into the fray. Although there are several established and workable approaches to calibration, different DIY groups often consolidate around one mode of calibration to which they lay claim. DIY groups also often refuse to recognize data as valid if sensors have been calibrated in ways other than their preferred method.

A focus on calibration reveals that what constitutes a "working" monitor varies widely both within and between DIY communities—from a device that operates well enough to produce some data to a device attuned to produce data about local environments to be formed into evidence about pollution. While DIY might seem to be about experimentation and generating multiple practices, it can as easily lock down into techniques such as singular approaches to calibration, which re-create many of the same power dynamics found within the expert-driven science within which DIY is meant to intervene. Calibration, in this sense, can become a normative practice vying for legitimacy within a market for air quality monitoring. It may be open to invention or experience in limited or contested ways. Rather, as with many normative practices, any queering or intervention within established practice is met with aggression (cf. Ahmed, 2017). However, as we have suggested here, the performance of calibration can be generative as it requires mutual adjustments and tuning of hardware, software, environmental conditions, and modes of use in relation to concrete social-political situations. This is not only a space of ongoing calibrations and re-calibrations but also an invitation to consider how to re-calibrate DIY practices so that they tune in to these multiple factors that influence the experience of sensors and sensing.

Conclusion: re-calibrating DIY practices

Within multiple DIY communities, air quality monitoring with digital sensors has emerged as a core focus. In some cases, this practice can involve an attention to the demands of learning DIY electronics, more than an in-depth engagement with environmental problems and affected communities. However, as our Dustbox deployment began to demonstrate, DIY air quality monitoring is not just a technically driven project, it is also a social and political one that is entangled with a rich genealogy of DIY and activist approaches to sensing air. These activist practices of DIY have highlighted the ways in which air quality sensors and the data they generate are not simply determined through universal criteria or standardized devices, but rather come to be relevant within specific environments and through distinct relations, as environmental media (cf. Gabrys, 2016: 266).

Moreover, feminist technoscience literatures demonstrate the partial and located nature of technology design and production. Calibration and re-calibration are, in this sense, forms of "artful integration" (Suchman, 2002: 99) where sensors require local alignment and integration to get them working. But as environmental media and tools of measurement, calibration describes an even more thoroughgoing *re-calibration* of sensing devices as they are tuned to environmental and socio-political conditions. Re-calibration also enfolds a politics of technique, where relationships and attachments to practices within DIY air quality monitoring communities can shape the claims that can be made about the legitimacy of environmental data.

Our approach to making prototype DIY sensors involved not just assembling a device for use but also engaging with the diverse relations and possibilities that emerge through operationalizing sensors (Gabrys, 2017b). This was a practice to think through the "performative characteristics" (Suchman et al., 2002: 164) of DIY prototyping. By rebuilding kits and gaining a sense of how to work with hardware and sensor configurations, we were able to observe the technical resources, capacities, and infrastructures these technologies require; the decisions that are made or elided in order to make the monitoring kits in these particular ways; as well as the domains inhabited to generate and circulate environmental data through these devices.

In the context of air quality monitoring, digital DIY tools have emerged as methods and applications that promise the possibility for expanded engagements in technoscientific practices. Through our engagements, we were able to observe the ways in which low-cost digital sensors and platforms organize and constrain DIY approaches to measuring air quality. In other words, the specificities of how participants engage with sensors and data came into much closer focus through the actual process of working with and calibrating devices.

Our research project has not been set up to build the latest proprietary technologies, nor does it espouse that digital sensors will save the world. We are, however, interested in how digital monitoring technologies organize environmental politics in order to work through how a/effective practices and politics might be developed or realigned. In this sense, we are invested in more inventive problem making (Stengers, 2011 [2002]) in order to rework, re-make, and *re-calibrate* the usual formulation of environmental problems. As a lens for future work, we point to how re-calibration continually re-surfaces the technical-social-political entanglements of sensing—as the re-calibration of sensors is constantly required long after other technological devices may have stabilized. This radical openness to milieus can be read as a call for more attentiveness to the unsettled politics of DIY practices. Calibration techniques take on different political valences: cutting and pasting fry-pan bacon code is very different to calibrating in situ with community groups concerned about environments. Re-calibration returns us to a feminist-technoscience-inflected politics of DIY that suggests measurement is not a solution in itself but redirects attention to the process of measuring: most importantly, what humans and more-than-humans are we undertaking measurement for, and with?

Such a strategy does not argue for a non-technological approach, but rather works through the sorts of practical commitments to which monitoring technologies commit us. Digital sensors are not simply universal devices for ascertaining the "truth" of environmental phenomena such as pollution. Indeed, they may even complicate the "facts" of what counts as pollution. Instead, these technologies are tied into an extended arrangement of practices, politics, communities, materialities, capabilities, and skills that require ongoing processes of calibration and re-calibration. Calibration and re-calibration are not just technical but also political engagements, which re-make environmental and civic life.

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