CULTURALLY SITUATED SENSING: Peer Innovation and Citizen Sensing in Native American Communities

by

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Submitted by Commission to the
Intel Corporation, Experience Insight Lab (XIL)
March 31, 2011

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1. Introduction

A broad spectrum of environmental sensor projects has emerged in the last decade as appropriate technologies become portable, economical, and accessible to non-expert users. As a result, there is national and international interest in sensor-based citizen science initiatives, or *participatory sensing*, capable of assisting under-served populations in addressing environmental concerns including soil, air and water pollutants in their communities [Burke, Estrin, et.al. 2006]. A quick scan of the field shows participatory sensing initiatives stemming from university research centers, private industry partnerships, and individual innovations alike. Most encompass an impressive array of deployment strategies: passive and active data collection, user-focused design of new technologies, green urban planning, as well as leveraging new forms of STEM education (Science, Technology, Engineering and Math) [DiSalvo, Sengers et al. 2009].

However, the usefulness of many well-intended participatory sensing projects is often restrictive when delivered to target communities. One reason may be that lay participants are typically dependent on external experts for producing sensory technology as well as for providing data analysis. But they are also restricted by limitations that precede the intervention, such as the complicated structure of joint managed environments, or limitations in their ability to collaborate for collective action. Citizen science projects are also marked by challenges in the gaps between data collection, data reporting, and effective action [Frickel et. al. 2010]. In many cases, the participatory aspects of citizen driven environmental monitoring campaigns end with the process of data acquisition. Pre- and post- considerations of how this data becomes contextualized remain secondary.

Technological features such as data visualization systems, crowdsourcing tools, and other methods for showing the interconnected aspects of community generated data are an important part of the solution. However, approaches founded on technical architectures without consideration for human factors create challenges at different levels [Dourish 2010]. Credibility and usefulness of participatory technologies are constructed as much by legal, political, cultural and economic constraints as it is by incremental amounts of available data or the deployment of ubiquitous sensor networks [Cashman et al. 2008]. Central to these shortcomings is a lack of critical engagement with local knowledge systems and practices. This paper will highlight a need to dynamically and contextually change the relationships between outsiders and insiders, to both build local capability as well as local access to external resources.

And yet, in considering new sociotechnical arrangements we must also question what it means to bring new technologies into Native American communities and the possible side effect this might have in shifting focus away from the survival of traditional and cultural practices. While much deserved criticism has been levied against "preservational" or deep ecology sentiments for "saving" indigenous life ways, some consideration should be made as to how ubiquitous sensor networks might alter Navajo perceptions of themselves and their environment for good or bad .

A new body of work is forming which may address these gaps in combining peer produced knowledge research, participatory design, and DIY appropriations of open technology. By suggesting this alternate framework for thinking about how local productions of scientific knowledge feeds into participatory sensor infrastructures, a set of required cultural parameters embeds itself into what architect Andrew Marsh calls

performative design, "deeply considering the wide array of building performance issues simultaneously with other aspects of the design right from the earliest, most formative conceptual stages." [Marsh 2008] Proactive theorizing, however, can go beyond intellectual exercise. As has been shown by scholars of "open source," products informed by performative design -- politically engaged programming -- have impact in both immaterial and material worlds [Kelty 2008]. In short, applying knowledge-in-practice and recursive design strategies may create greater potential for participatory sensing as an activity of self-determination.

Knowledge-in-context projects are particularly relevant for Native American communities, the focus of this paper. Exploring how the complex interwoven nature/culture relationships in indigenous communities will interact with participatory development of environmental sensors is a unique investigation worth broader attention. Despite a pressing need to address severe environmental concerns on Native lands, skepticism is a major barrier to acceptance of outside assistance. Much of this is due to the well-documented history of negative impacts resulting from negotiations with non-native parties working "in their best interest". Finding a locally driven approach, both in sensor technology adoption and application, could prove essential in altering these relationships.

Empowering indigenous communities as activists is also one of the best ways to counter the structural racism that threatens indigenous people and culture. Identifying the potential for a strategy this paper refers to as *Culturally Situated Sensing* may therefore promote wider distributions of indigenous knowledge, as well as break down assumptions that indigenous science is somehow distinct from or inferior to Western technological practices [Watson-Verran and Turnbull 1995]. Meanwhile, internal to these communities,

using a Culturally Situated Sensing framework has greater potential to raise the awareness of younger generations not currently engaged in their traditional heritage. While the Native American examples addressed herein allow for a microanalysis in one community, similar limitations and benefits apply to citizen science campaigns elsewhere. This paper therefore aims to project the usefulness of Native American Culturally Situated Sensing as a tool for broader application.

2. Methods of Analysis and Critique

Emphasizing an early synthesis between technical and social issues -- also a fundamental charge in the academic field of Science and Technology Studies -- is perhaps the most direct intent of this paper, and it is from the perspective of an organized STS critique our analysis will follow. First, although there is a large body of literature in STS and other fields on participatory design, as well as a growing body of work on participatory sensing approaches, there are limited intersections. Second, while there is interest in STS concerning indigenous cultures and ethnic/racial dimensions of science and technology, a narrow band of research exists on technically driven environmental science carried out by Native American communities. Native American technology-based citizen science does indeed exist in limited application and has the potential for wider expansion. Third, current citizen science paradigms for community activism require further inquiry against homogenous assumptions of how "lay expertise" is constructed in context with indigenous knowledge systems. This paper will make connections across disciplines to provide a review of case studies and hopefully illustrate terrain for participatory sensing research with this broader range of considerations.

Finally, this paper discusses the issues of power dynamics and constructing credibility. By mapping indigenous environmental science as a partnership between local and external associations, we can question how culturally informed technical approaches and new forms of data acquisition can negotiate relationships between social institutions, as well as how these projects can remain locally controlled and contextualized [Brewer and Dourish 2008]. All of the above will offer new insights into peer production, citizen science, and practices in environmental sustainability, as well as illuminate practical application of these fields in multiple contexts.

3. Environmental Vulnerability on the Navajo Nation

Archaeological evidence suggests that the Navajo people (Diné) have lived in their current location for at least 1,000 years. They are the second largest Native American tribe of North America, with an estimated population of 300,000 people identifying as Diné. According to the 2000 US census 180,462 Navajo still live on the reservation spanning 27,000 square miles across 3 states -- the remaining in bordering towns or nearby cities [Navajo Nation 2000]. The Navajo Nation is represented by an governing body consisting of many of the functions one would expect of neighboring states -- an independent Navajo EPA, police force, judicial system, as well as elected officials at local, regional, and national levels. Meanwhile, the Navajo language is still spoken throughout the region and many of their traditional practices remain integral to daily life such as sheep herding, rug weaving, and crafts.

However, despite geographic solidarity as compared to other Native American tribes, the Navajo are threatened by a litany of environmental hazards put in motion by

decades of unmonitored energy and mineral extraction industries. Twenty-five Native American territories throughout the United States contain extractable coal deposits accounting for a potential 30% of all national reserves, with Navajo Nation mining facilities ranking as some of the largest [Office of Technology Assessment 2002]. The density of natural resource extraction is astounding in some areas. Paradox Basin, a region of about 33,000 square miles overlapping the Navajo Nation in southeast Utah, is home to some 6,000 oil and gas wells according to the Dine Environmental Institute.

Nearly a century of uranium extraction maintains a legacy of 520 mines on the Navajo Nation according to the United States Environmental Protection Agency -- although environmental justice group Forgotten People claims this number is closer to 1,300. Most uranium mines remain unmanaged in a state of abandonment and many in close proximity to nearby villages [Diep 2010]. Navajo uranium extraction is now prohibited under the Diné Natural Resources Protection Act of 2005. But with nearly 37% of all uranium in the US estimated to exist on or abutting Native lands, increasing demand by the nuclear energy industry has pushed growing interest in reconsidering future mining [Smith 2007].

In addition to poorly managed resource extraction, the prevalence of coal on the Navajo Nation supports a series of power generating stations including three of the largest in the Southwest -- Four Corners, San Juan, and Navajo Generating Station -- for a combined output of more than 6,000 megawatts supplied to half a million people in nearby cities. Consuming over 100,000 tons of coal per day and a combined water use in excess of 16 billion gallons annually, these three sites rank as some of the greatest sources of air pollution in the country. A 2004 comparison showed Four Corners Station ranked as the single highest emitter of NOx of any power facility in the United States, and the 24th

highest for carbon dioxide. Meanwhile Navajo Station ranked 11th in NOx in the US and 5th for carbon dioxide emissions [Milford et.al. 2005].

4. Public Health and Issues of Dependency

The severity of environmental impacts on the health of the Navajo people can hardly be overstated. Records collected by The New Mexico State Tumor Registry dating back to the 1970s shows a 17-fold increase in childhood reproductive cancers on the New Mexico portion of the Navajo Reservation, when compared to the U.S. average [Williams 2008]. A 1998 health survey of 896 households bordering oil fields on the Paradox Basin in Aneth, Utah (population 2,236) found complaints of upper respiratory distresses, dermatological conditions, musculoskeletal inflammations and psychological concerns far exceeded US averages.

In 2007 a study by Northern Arizona University on uranium endocrine disruptors linked decades of mining to growing contamination levels in water supplies across the Navajo Nation [Raymond-Whish, et. al. 2007]. Additional studies suggest some 40% of unregulated Navajo water sources exceed drinking standards for arsenic and 11% exceed maximum allowed uranium levels [Walker and Carroll 2011]. Meanwhile, the Navajo EPA estimates that up to 30% of its population draws water from unregulated sources such as private wells, nearby springs, and livestock collection tanks [US EPA 2011].

Under social pressures including 42% unemployment and 42% of families below the poverty line, the Navajo people remain economically dependent on extraction and energy industries. More than half of the Nation's annual General Fund comes from oil, coal, gas, and heavy metal mining royalties: $71.34 million out of $124 million as of 2005 [Liu

2010]. Native Americans account for 83% of employees in mining operations across the Navajo Nation and 80% of employees across the three mentioned power plants.

Furthermore, conflicting opinions complicate potential environmental justice efforts as anti-economic. In 2009, for example, then President Joe Shirley Jr. ejected the Sierra Club and other environmental action groups from the Navajo reservation over concerns that their agendas damage local economies and revoke Navajo authority, "our greatest opposition comes from environmentalists [who] don't know about Navajos, sovereignty or self-determination. They just want any use of coal stopped. However, coal is the Navajo Nation's most plentiful resource, and our prosperity depends on it." [Hardeen 2009] In March 2011 incoming Navajo President Ben Shelley (Shirley's former VP who ran and defeated the progressive New Mexico State Senator Lynda Lovejoy) signed a new 25-year lease for the Four Corners power plant, securing 700 jobs and Tribal government revenues, despite concerns that the 50-year-old plant has far passed its intended life expectancy [Slothower 2011].

5. Diné Natural Law as Collective Responsibility

> *We, the Diné, the people of the Great Covenant, are the image of our ancestors and we are created in connection with all creation.*
>
> *The Holy People ordained,*
> *Through songs and prayers,*
> *That*
> *Earth and universe embody thinking,*
> *Water and the sacred mountains embody planning,*
> *Air and variegated vegetation embody life,*
> *Fire, light, and offering sites of variegated sacred stones embody wisdom.*
> *These are the fundamental tenets established.*
> *Thinking is the foundation of planning.*
> *Life is the foundation of wisdom.*
> *Upon our creation, these were instituted within us and we embody them.*

Diné Natural Law (Nahasdzáán dóó Yádilhil Bits' ádáde'e' Beehaz' áanii) embeds a sacred respect for the environment and all living things as the fundamental responsibility of the Navajo people. It is one of four components outlined in the Navajo Nation Code (Diné Bi Beenahaz'áanii) illustrated by the introduction seen above [Navajo National Council 2002]. Tribal courts place DNL as a higher power over individual constitutional rights and the fact that the Navajo have no written constitution partially reflects this.

Navajo legal history shows resistance to individual rights is due to social constraints as well. A lack of consensus on how constitutional clauses might impact tribal authority in negotiating with US federal agencies is one barrier. Another is more practical -- limited resource and a dispersed population restricts clear forms of representation and governance in more remote areas [Wilkins 2002]. As a result, few parameters exist for how DNL should govern daily environmental issues relative to individual claims. But the existence of DNL sets a general tone of respect and stewardship to preserve native lands for future generations and permeates most grass roots Navajo environmentalist efforts [Barbroff 2004].

However, in 1995 environmental regulatory jurisdiction passed from the United States Environmental Protection Agency to the Navajo EPA (NEPA). This necessitated practical codifications of Navajo environmental management, also resulting in the Navajo Nation Environmental Policy Act. While in spirit an agency of holistic responsibility, NEPA is by and large seen as a reflection of its federal predecessor; favoring inherited Western scientific models and economic considerations over Diné *hozhó* (balance).

An illustration of this divergence can be seen in the struggle to shutdown plans for the proposed Desert Rock coal-fired power station. Unlike Four Corners, Desert Rock would have been a co-owned facility with power companies. To secure land for the plant the Navajo government reportedly coaxed elderly sheep farmers to sign over grazing rights while hiding the project's intentions. In 2008, the US EPA, in consultation with Navajo NEPA officials and the Diné Power Authority, issued statements that the additional plant would not impact air quality in the region. This prompted a successful lawsuit by the Diné Citizens Against Ruining Our Environment (CARE) coalition, which succeeded in slowing the plant's development. Even so, it was a financial consideration -- the Navajo Nation was unable to provide its share of matching funds -- that killed the plant's construction [Jackson 2010].

Without the support, and in some cases open hostility, of Navajo government agencies, environmental justice groups must navigate numerous logistical issues. Lack of electricity in remote areas hamper communications and undermines participation at public hearings. The absence of local funding sources (most revenue goes to tribal government) limits the ability of residents to hire attorneys familiar with Navajo law. Ultimately, limited access to alternative news sources and publicly available information often means externally driven development goes unquestioned [Monestersky and Yellowman 2010].

Billy Reese Key, Chairman of the Forgotten People Community Development Center, suggests the lack of respect for DNL poses additional challenges for citizen action groups looking to find traction in their native heritage. In the case of Desert Rock, cultural parameters defined in environmental impact statements were limited to federally recognized sites of religious, historical, and protected species importance. This resource-

specific EIS, prepared by experts on the payroll of energy company Sithe Global Power, neglected the mandates of DNL to the detriment of Navajo residents who draw fewer boundaries between nature, history and geography.

Forgotten People suggests one strategy for reintegrating DNL is to develop a *native environmental justice* where one can conclude, "the goodness or badness of a given thing by looking at its effects," thus placing traditional sociocultural evaluations at the forefront of what constitutes positive *effect* [Kee 2008]. Critics point to the inadequacies of relying on subjective observations for identifying air, water and soil pollutants. This is a point worth noting in the context of participatory environmental sensing given many toxic parameters require technical qualification to justify action.

Other groups, like the Black Mesa Water Coalition, have taken native environmental justice to mean a return to DNL-inspired sustainable ways of living. BMWC successfully lobbied the Tribal Council in 2009 to establish the Navajo Green Economy Coalition under pressure to create jobs independent of extraction industries. By seeding renewably energy projects, greening local manufacturers, and modernizing Navajo agriculture, groups like BMWC are making a bid to retain younger generations on the reservation.

The success of NGEC and similar sustainability projects remains to be seen -- in its current state NGEC receives no Council funding and only two of its five commissioners played key roles in the project's development. What is perhaps more relevant to our understanding native environmental justice was BMWC's unprecedented grass roots success -- nearly 1 in 4 local governance chapters endorsed and gave financial support to their campaign [Liu 2010]. BMWC's ability to mobilize chapters historically resistant to

unification efforts gives hope that environmental justice could be the key to creating future solidarity in the Navajo community.

6. Social Movements and Communities of Expertise

Sustainability projects such as BMWC's Green Jobs Coalition may do less to address preexisting environmental hazards as might Forgotten People's struggle against coal, but social movement scholars recognize the need for presenting alternatives. Practical and forward-thinking solutions are the leveraging capital of groups contesting default but misaligned practices. Alternative social movements, as described by David Hess, share a set of common strengths that revolve around the foundational power of localism. Movement organizers draw upon extensive pre-established social networks with strong but isolated political connections at regional and national levels. Environmentalist groups pushing new technologies as part of their solution often prove the success of their projects in regional test cases with early adopters [Hess 2007]. Successful movements build on these foundations to continually partner with other activist groups, researchers, and private innovators to create pathways to hybrid organizations capable of reaching across institutions and geographies. The nature of hybrid partnerships, however, is one of collaboration between individuals with often-conflicting ideologies and experiences. This has necessitated a broader definition of how we define *expertise* and *knowledge* across this range of perspectives.

A well-known case study of lay knowledge in environmental controversy is Brian Wynne's extensive writings on the troubles faced by Cumbrian sheep farmers in the wake of the 1986 Chernobyl reactor disaster. In an unusual series of atmospheric events, a

significant portion of radioactive fallout settled among sheep farming communities in northern England. Faced with public health uncertainties, government officials quarantined flocks pending rapid reductions in contamination as predicted by scientific experts. Meanwhile farmers found their way of life threatened by decisions beyond their control [Wynne 1996].

Wynne uses the Cumbrian study to illustrate how scientists and policymakers failed to acknowledge the useful contributions of farmers in monitoring their animals. Local expertise was instead marginalized as culturally informed but scientifically impertinent to predetermined methods of agricultural testing. In return, members of the farming community were quick to discredit what they perceived to be a secretive and inconclusive scientific process [Wynne 2006]. Wrapped in a series of extended government mandates, botched experiments, and a growing skeptical community, the Cumbrian study stands as an iconic example of how unsuccessful mediations between lay and expert knowledge can prevent meaningful action.

The question of what constitutes *lay expertise* therefore comes under scrutiny as we evaluate public contributions to scientific projects. Critics of Wynne state that the notion of lay expertise is an illusion -- romantic views of traditionalism do more to historicize and colonize local knowledge than aid in their contemporary applications [Durant 2008; Harding 2008]. Sheep farmers, for example, would not consider themselves laymen of science, but instead experts of farming. By establishing a definition of expertise inclusive of local practice, the latent value of lay participation expands beyond momentary disasters and develops greater traction for long-term symmetrical inclusion in scientific debates [Collins and Evans 2004].

7. Passive vs. Independent Citizen Science

New forms of public engagement commonly referred to as *citizen science* become possible as local scientific knowledge production gains the necessary credibility to be considered relevant in broader scientific debates. Kelley Moore poses two possible constructs for how we might classify citizen science. The first is activist in origin: efforts negotiated by established organizations, where professional scientists become partners as invited by the movement's organizers. These scientists are chosen based on their ability to provide expertise relevant to specific problems identified by the group.

However, a number of limitations arise in this process of "enlistment." First, an external researcher's subject of study may differ from what activists see as the core issues. This may be particularly true in the case of scientists working through private firms with embedded financial incentives. Second, scientists may hold different notions of what constitutes relevant data based on the metrics of their research. The process of enlisting scientists for knowledge production may there be seemingly local in origin, but can quickly become defined by the agendas of external researchers [Moore 2006].

A good example of oppositional fact-finding can be seen in Barbara Allen's comparison of environmental health studies conducted in the Louisiana Chemical Corridor. Early citizen-driven efforts used community mapping and zip code studies to accumulate personal testimonies from affected residents. Alarming illness trends generated enough attention to enlist more in-depth public health studies by Louisiana State University, the Louisiana Tumor Registry, and other groups who focused the majority of their attention on cancer studies -- to the extent that the region is also commonly known today as Cancer Alley. These studies found, however, that cancer rates were relatively on par with national

averages. In contrast, studies done on illnesses identified in the original community mapping projects showing extremely high occurrences of other non-cancer related complicating diseases. Nevertheless, the conclusiveness of the LSU and LTR findings favored local petrochemical industries and created a climate where alternative community based interpretations were easy to dismiss [Allen 2003; Allen 2004].

A second construct for citizen science, "amateur science," sheds light on the viability of another *kind* of local expertise akin to vocational knowledge, "produced by people who are not paid to produce knowledge." [Moore 2006] However, detractors including Moore point to the common assumption that amateur produced scientific knowledge can only functionally support or denounce professional science -- such as the century-old annual Christmas bird count by the National Audubon Society -- but not produce a *science of its own*. Framing local expertise as amateur in spirit disallows local control beyond the ability to shift externally driven research agendas [Morello-Frosh, et.al. 2006]. This falls into the same trap as inadequate and liminal terms like *lay expertise*. Both activist group and amateur generated scientific knowledge may produce *forms* of cognizant citizen science, but both are characterized by passive and/or reactive contribution by the community.

A number of projects attempt to resolve the problem of passive citizen science. For example, the Louisiana Bucket Brigade continues to serve as a model program for extending public participation in environmental justice, but not without its complications [Ottinger 2009; Ottinger 2010]. In the months following Hurricane Katrina, inconsistent and limited EPA monitoring of toxic chemicals spread by the disaster whitewashed community concerns [Frickel and Vincent 2007]. Deploying relatively inexpensive air collection buckets into the community greatly increased the scope of monitoring

capabilities and favorably turned political decision-making. Yet, organizers of the project also admit to the limitations of relying on laboratories to analyze samples, and the difficulties of having non-expert citizens interpret complicated data reports. As passive recipients of knowledge, citizen "collection" projects diminishing the potential impact of time sensitive data. The community's inability to fully understand applied technologies also prevents future adaptation as researchers enter and exit the field [O'Rourke and Macey 2003].

A recent collaboration between the Bucket Brigades and a partner group working to document the 2010 Gulf Coast oil spill attempts to deal with the laboratory dependency issue. The Grassroots Mapping project hopes to place more knowledge production in the hands of community groups by launching cameras kits in helium balloons to collect aerial photographs of environmentally sensitive areas. The goal of the mapping team is to then do real-time comparisons with spectrometric, infrared, and thermal imaging through online data analysis tools and crowdsourcing systems [Public Laboratory 2011]. Early tests of the kits have shown a great deal of success in allowing participants to collect and engage data in new ways. But the extent to which these strategies allow the public to make sophisticated discoveries -- as opposed to through professionally analyzed results -- remains to be seen.

8. Community Based Participatory Research

Jason Coburn makes the point that communities often reject the idea of "scaling up" or generalizing personal experiences and practices in order to build a movement's coalition and enroll external support. This is based in a fear that decontextualizing local expertise

produces oversimplifications of heterogeneous worldviews and neglects the importance of heritage [Coburn 2005]. In suggesting a more proactive model of participation we must ask: what then is at stake in de-marginalizing native citizen science? How might the Navajo incorporate hozhó to further the credibility of local knowledge production and counter dismissals of their heritage as nonscientific? Furthermore, does embedding cultural parameters allow for a scientific knowledge incorporating different traditions and technologies, but at the same time forming a unique and independent technoscience of its own -- a Navajo site of scientific expertise? In considering new models for leveraging the assets of citizen science projects we must consider the ways in which hybrid relationships can form useful partnerships between local experts, external researchers, and activists. The same holds true for innovators of participatory technologies. Citizen driven agendas with closer connections to Diné Natural Law could allow Navajo ways of understanding the environment to span hybrid institutional partnerships and create locally rooted solutions capable of operating at various scales.

Community-based participatory research (CBPR) perhaps shows a way through some of the dilemmas mentioned above and opens doors to similarly conceived participatory designs for technology discussed later. CBPR is a hybrid approach, drawing upon diverse participants to "co-produce" knowledge which then becomes useful for both community and external stakeholders [Jasanoff and Wynne 1998]. Unlike focus groups or public inclusion methods, participatory research acknowledges different kinds of expertise as well as their role in prioritizing issues and forming solutions. A critical component to CBPR is an emphasis on social transformation through capacity building across hybrid partnerships to form robust coalitions for common cause [Minkler and Wallerstein 2003].

This strategy has become particularly useful in developing technical education partnerships in Native American communities.

Indian Summer, a river fish recovery project initiated by Ed Galindo and the Shoshone-Bannock people of Idaho, ran for more than six years with community members and local high school students. Salmon and steelhead populations in the region were in dramatic decline, generating concern among protected species groups and native fishing communities. As a participatory research project, Indian Summer conducted culturally and environmentally sensitive studies to revitalize not only important fish populations, but also to foster a greater consideration for what these species represented to the Shoshone-Bannock people [Galindo and Barta 2001].

The groundwork for cultural components was established prior to any technological decisions. Shoshone-Bannock elders provided academic programming including ceremonies intended to tap into the "circle of life" by communicating with the fish through prayer rituals. Meanwhile, students applied technoscientific components to communicate in parallel ways through streamside incubators and sensor technologies tracking migration patterns. Information on migration patterns was also informed by the inherited knowledge of local fishermen. The hybrid model of applying expertise in Indian Summer is considered a success on two levels. First, participants became more aware of their cultural heritage and how it pertains to technoscientific practices often seen as external to native communities. Second, through local applications of contemporary technology, the project was able to scale their efforts regionally to release some 60,000 fish over the five-year life of the project [Barta and Brenner 2009].

Applying technological approaches in citizen science does reduce dependence on external interests and certainly puts valuable resources into communities of need. In the case of Indian Summer, culturally defined programming combined with readily available monitoring tools to form successful hybrids accessing expertise on multiple levels -- both internal and external to the Shoshone-Bannock community. But shifting to technological solutions could inadvertently replaced dependence with instead a reliance on tools harboring mismatched research agendas similar to those seen in Cancer Alley. A research team sending out a fleet of CO2 detecting infrared cameras to monitor air quality around power stations, for example, might miss altogether the presence of ground level volatile organic compounds -- with similar undermining consequences as truth making devices. For developers of dynamic community-based research projects, a mandatory consideration should not only be how co-produced knowledge gets incorporated into citizen activist programming -- but also into the design of technologies being deployed.

9. Politics and Performative Design

CBPR projects like Indian Summer is in line with a tradition of research which has shown great success for promoting culturally sensitive Native American STEM education. A similar project, the Culturally Situated Design Tools of Ron Eglash, uses software tools emulating rug weaving and bead looms to teach students mathematical concepts like four-fold symmetry and iteration on the Cartesian coordinate system [Eglash 2009; Barta and Eglash 2009]. Whereas mathematics are often perceived as rooted in Western science, the CSDTs illustrate similar systems have existed in Native American practices for generations -- the four holy mountains to the North, South, East, and West define the borders of the

Navajo spiritual universe for example. As educational tools informed by educators in Native American communities the CSDTs are, "dynamic rather than static views of culture," and are often partnered with demonstrations by native practitioners. This collaborative reflexivity is evident in instances where software tools have required adjustment as informed by native design [Eglash et.al. 2006].

When we talk about collaborative building of technologies, CBPR practices resemble similar intentions seen in participatory design (PD) strategies akin to how the CSDTs incorporated Native American expertise. Here, user input becomes a primary component in the lifecycle of research and development. PD has proven to be a useful alternative to commercial design models and better reflects a user community's expectations and culture. However, a number of questions continue remain unanswered even as participants become part of the co-production equation. Due to the cost and time constraints of fieldwork-oriented design, user participation is often limited to a narrow set of activities in the overall development cycle [Kensing and Bloomberg 1998; Kensing 2003]. Here, users are seen as valuable data points, but direct control over the end product and how it will ultimately be deployed is left to designers. The intentional short-term nature of PD engagement projects also prevents users from gaining prolonged experience with the technology and reinforces dependence on external developers [Cooke and Kothari 2001]. Contrary to how CBPR addresses the design of co-produced knowledge to ensure accessibility for all parties involved, the possibility for scaling up PD solutions to a broader community are limited by making compromises to user control in the full cycle of development. This is particularly true in the case of manufacturers of proprietary

technology who fear losing control of their designs as they go to market [Baldwin et al. 2006].

Participatory design raises other challenges that are especially relevant to citizen sensing projects. Functionally reduced prototypes can result in small-scale applications with limited functions for relevant fieldwork. Many sensor projects -- particularly ones of artistic origin -- are effective at demonstrating the *potential* for participatory sensing with "in-development" devices built collaboratively with users (see for example Natalie Jeremijenko's Feral Robot Dogs or Urban Tapestries) [Jeremijenko 2011; Silverstone and Sujon 2005]. But these projects do more to gain insight for future inquiry than offer meaningful solutions -- in this respect they become more performative than utilitarian and could serve to undermine environmental justice in ways seen in Cancer Alley. Nevertheless, performative projects have benefits as well. By engaging the community in ways that foster better understandings of their environment and the role they play in shaping its future, participatory sensing, even when limited in function, can play a key role in civic activism.

This approach has become a hot topic in participatory sensing in recent years and a diverse field of research has erupted on the subject [Campbell et.al. 2006; Aoki and Honicky 2009; Martin et.al. 2010]. One example, the Neighborhood Networks Project, was launched in 2007 as a partnership between design researchers at Georgia Institute of Technology and the Robotics Institute at Carnegie Mellon. The intent of the study was to use low-cost hardware platforms to construct sensor "Canary" kits and assist Pittsburgh residents to think critically about city air quality. Workshops participants were given hands-on projects with sensor equipment as well as shown how to use simple mechanical components to build ad-hoc robotics responsive to environmental parameters [DiSalvo et.al. 2008]. The

project proved successful on a number of levels. As non-experts in mechanics or electronics, participants gained a great deal of knowledge relevant to technical devices they encounter on a daily basis. Hands-on exposure to sensors and their reactivity in different contexts also allowed participants to consider multidimensional views of their environment. Most interesting, however, was the performative value of the project. While users were developing their prototypes of environmentally sensitive robots, the research team integrated personal storytelling and community mapping activities to locate the user at the center of a critically thinking design process [DiSalvo et.al. 2009].

10. Expert Users and Democratized Design

Research has shown that by centering design to adapt to local needs -- or tapping into "expert user" affinities for modifying technologies -- participatory design can become more reflexive. Expert users exist on the forward edge of important trends and have needs that will later be experienced by many. While the typical user is accustomed to technologies working correctly "out of the box," and adjust their expectations accordingly, expert users are comfortable with adapting standardized products to obtain personalized solutions. Eric von Hippel and other proponents of expert user theory, or *lead users*, believe that designers using reduced prototypes in ideal settings miss opportunities for seeing these kinds of on-the-ground adaptations of their products. As a result, they fail to take advantage of adaptable innovations as a way to *design-in-practice* such that a "prototype" and the technology in everyday use become indistinguishable [von Hippel 2005].

User innovations are the product of heterogeneous communities -- variations in technical expertise, available resources, and local design requirements spawn not one, but

a series of unique solutions [Anderson 2006]. Nevertheless, while local parameters may vary, innovator collaborations tend to have an outwardly spiraling effect, enlisting additional users, manufacturers, and other contributors to their project as usefulness scales up to attract a wider audience. In this way, user innovation communities closely resemble alternative social movements in their ability to create hybrid arrangements across institutional boundaries. The flipside to designing in practice with a community of users, of course, is that manufacturers of proprietary devices must relinquish a certain degree of control in their designs. While proponents of democratic technology see this as a good thing, practical considerations for how profits can be made from such models have not fully matured.

If community based participatory research recaptures cultural parameters in citizen science and centers ownership within local expertise, then user innovation does the same for creating locally controlled designs of technology. The two are components of a growing movement defined by an umbrella of terminologies including DIY (Do It Yourself), critical technical practice, and critical making [Kuznetsov and Paulos 2010; Agre 1997; Sengers et.al. 2005; Ratto 2008]. None of these frameworks are entirely satisfying in their analysis, but all have their ideological roots in hacker culture -- paying homage to the basic tenets of "free software" philosophies laid down by Richard Stallman and early developers of GNU licensing.

The debate over free software arrived with the milieu of competing interests in software design, with private developers pitted against self-identified hackers of their products. The former viewed the problem as a matter of securing ownership of their designs, but the latter framed the debate as a fight to protect inalienable rights to creativity

and to maintain democratic access to technology [Stallman 1992]. These same arguments are echoed today by technology-oriented activist groups in CBPR citizen science: enabling disenfranchised communities to engage social issues by applying technological solutions requires the freedom to innovate and adapt. Restrictions put in place by closed designs therefore runs counter to the idea that community mobilization can be scaled up to incorporate new technoscientific resources [Gillespie 2007]. Furthermore, closed designs block local expertise from negotiating alternative meanings into existing knowledge systems.

11. Peer Innovation and Appropriating Technologies

Two revolutionary phenomena are exploding these sentiments into mainstream popularity and have sweeping intellectual as well as social significance: commons-based peer production, and DIY appropriations of technology. Open source software, as well as open hardware platforms such as Arduino microcontrollers, has become the primary driving force behind contemporary commons-based peer production communities. Crowdsourcing and resource pooling have revolutionized our understanding of how information systems can be developed through bottom-up processes, voluntary associations, and public ownership [Benkler and Nissenbaum 2006]. An attractive characteristic of commons-based materials is that they are often used for social benefit and are provided at low or no cost to the user. This offers under-served communities new opportunities to overcome the digital divide and provides avenues for greater access to tools enabling social empowerment [Benkler 2006].

Meanwhile, the popularity of DIY culture has evolved from scattered hobbyists to large scale gatherings as seen in Make magazine and its associated Maker Fair, online resource sites such as *Adafruit*, *Sparkfun*, *Hackaday*, *Instructables*, and even scientific endeavors like the DIYbio community [DIYbio 2011]. One of the most compelling aspects of activities in this culture is their ability to operate effectively in the hardware-populated material world: DIY innovators often use whatever materials happen to be locally at hand. As a result, these "appropriated technologies" [Eglash et.al. 2004] can spread rapidly within a community relatively free from institutional restrictions.

These two domains have complementary advantages and disadvantages. Commons-based peer production projects have demonstrated an extraordinary ability to tap into the "wisdom of the crowd" and deliver products with ethical intentions dedicated to the results becoming property of a public domain [Benkler 2006]. But non-proprietary purity is also a limiting constraint: open source projects generally require a total commitment the commons, and thus rarely create hybrid systems by barring the participation of proprietary industry and research. In addition, open source originated from -- and still works best upon -- information products such as software and media created in a "non-rival" economy rather than with material objects which require a more significant financial investment by either developers or users [Thompson 2008].

Appropriated technologies have the opposite limitations: although they are able to utilize and adapt a wide range of locally available material hardware, they rarely evolve into large-scale peer production efforts. Appropriated technologies do make strong use of social network systems. The YouTube video for "Making an LED Throwie" for example -- a simple but effective electronic device behind the well-known Aquateen Hunger Force bomb

scare -- lists over 1.5 million downloads [Lewis 2011; Smalley and Mishra 2007]. But these distributions tend to foster replications by other individuals rather than the long-term evolutionary peer-produced systems that we see in the open source community. Rather than a focus on social benefits and under-served populations as we see in the commons, DIY appropriated technologies tend to be artistic, intellectual experiments, or at best serve as proof of concept for a device that might gain traction in some other mode of production. This is not unlike characteristics discussed previously in performative-oriented participatory sensing projects. Technologies of individual appropriation and those existing in the commons are not entirely exclusive, but projects exploring how their fusion might facilitate social empowerment suggest the potential rewards could be dramatic.

Peter Semmelhack, founder of *Bug Labs*, a leading manufacturer of open source hardware, sees this as the key to long-term success in participatory technologies. While the current state of open source hardware, for example, rests on a few commonly used technical standards – most prominently the Arduino microcontroller -- there is remarkable variability in how those platforms are being used to build custom devices in the user community [Semmelhack 2009]. As an illustration, Leah Buechley's Arduino-based, wearable computing LilyPad toolkit presents compelling evidence of how open technologies are reducing barriers of entry by placing a striking amount of technical power in the hands of amateur users. In a study of LilyPad users, Buechley's research team discovered the majority of those surveyed believed their projects would not be possible before LilyPad's arrival. Even more interesting is how few users considered themselves part of a design community before working with microcontroller technologies but felt empowered by doing so [Buechley 2009].

Lilypad has since been used in a variety of applications characteristic of hybrid user innovations. WearAir, an “expressive” T-shirt design by a group of engineering students, monitors levels of air pollution and displays results through creative interactive clothing [Kim et.al. 2011]. Other projects are more applied in nature, incorporate proprietary components as well as found objects -- some even spawning copycat versions of the Lilypad platform to suit specific implementations [Buechley 2010]. A quick scan of the Arduino user community corroborates Buechley’s findings and suggests that the merger of open platforms with appropriation is widening the definition of what it means to participate in the design of socially critical technologies. It should be stated that while the published examples mentioned here represent work done by design teams in private, public, and educational settings, numerous less documented projects have proven equally vibrant.

The Lilypad community and others like it serve as useful demonstrations of new arrangements in user-designer peer innovation. Even so, case studies of this variety are incomplete as examples where local expertise and culturally situated considerations become central to the direction of large projects. The benefits of open platforms are evident in spreading the popularity of Lilypad for example, but widely distributed culturally informed appropriations have yet to emerge. Further work is needed to develop clearer pathways for inserting these cultural parameters into technical infrastructures even as they evolve to accommodate hybrid combinations of informational/material and proprietary/public components in various user-driven applications.

12. Constructing Credibility for Diné Natural Law

A 1997 survey of Navajo families with children suffering from asthma offers some insights into the complex relationship between traditional and contemporary factors that play out in Native American daily life. The study, led by David Van Sickle at the University of Arizona, found that almost half of interviewed families had brought their children to traditional healers at least once for treatment -- more than a third reported medicinal herbs as a viable option for relieving asthmatic symptoms. And yet nearly all survey participants were actively using biomedical inhalers as well. The combined approach can be credited to traditional Navajo beliefs that view sociocultural or individual imbalances as the site of communal and personal illness. This generally opposes biomedical considerations, which instead treat diseases by alleviating symptoms. While Navajo families were shown to consider biomedical options useful for immediate relief, most viewed the secondary benefits of restoring practices of Diné *hozhó* as critical to the long-term health of not just their asthmatic children but for their community as well [Van Sickle, et.al. 2003]. Considering the recent push by the National Institute of Health for medical practitioners to consider lifestyle habits and non-pollutant environmental factors in their treatment of asthma, the expert credibility of Diné *hozhó* assessments become increasingly convincing in its ability to contribute to contemporary scientific discourse [NAEPP 2007].

The Navajo Asthma survey has interesting implications for credibility in other ways as well. Two of the ceremonies identified by the survey used in the treatment of asthma, the Lightning Way (hóchxó'ííjí) and the Navajo Wind Way (Diné binílch'ijí), had been historically prescribed for chest and throat ailments caused by lightning, wind and other weather related triggers. Meanwhile, a recent set of studies published by the University of

Georgia and the British Medical Journal -- culled from six years of emergency room statistics compared with recorded weather events -- medically suggest for the first time that lightning storms can indeed trigger asthma attacks in some patients [ScieneDaily 2011; Altman 1996].

To triangulate the meaningfulness of these paralleling relationships we might conclude by drawing upon a more recent project by Van Sickle, *Asthmapolis*, which allows asthmatics to mount a simple GPS device to their inhaler. When pressed, data is sent to the project's website where user can then record and chart their symptoms. The Center for Disease Control and Prevention is now funding Asthmapolis, "to map and characterize asthma in rural areas of the Midwest," in ways not unlike how we might perceive a daily weather reports -- air quality warnings could be predicted in advance by tracking asthma attacks in neighboring regions for example [Asthmapolis 2011].

13. Pathways to Native American Culturally Situated Sensing

Original designs for the Asthmapolis GPS-enabled inhaler were far from complex. In fact, the idea came out of an undergraduate engineering course taught at the University of Wisconsin-Madison, using components readily available in the open source hardware community [Smith 2009]. One might ask then: if similar tools and resources were made available to Navajo citizen science groups, what discoveries might be made similar to the traditionally understood story of lightning induced asthma? Furthermore, how could Navajo appropriations of simple but effective technologies enable community based participatory research offering long-term sustainable solutions when applied to matters of environmental justice? Rug weavers, for example, still make use of native plants and

minerals for dyes, and cart their own wool to make yarn. GPS modules mounted to inhalers might just as well be used to track sheep grazing patterns, to protect endangered species, or to map out sensitive regions that have been damaged by extraction industry pollutants.

Processes of peer innovation and appropriation bear a striking resemblance to practices that reinforce these kinds of cultural, historical, and environmental connections within Navajo culture. First, storytelling as an iterative and evolving public memory device operates similar to accumulated knowledge networks in the open source commons. As the primary method for maintaining Navajo culture for over 1,000 years, storytelling remains an integral component of daily life. This is evident in the complex system of ceremonies and prayer rituals still practiced today [Spickard 1991].

In formulating culturally situated sensing projects, participants might reconsider the value of telling and documenting of stories. This could prove helpful for identifying what unique challenges exist in their environment, and could be useful in categorizing what they may or may not expect to find in the application of sensor technologies. Also embedded in the storytelling process can be found a rich history of how a community has historically developed its relationship to its environment as well as what internal and external factors have changed that relationship [Srinivasan et.al. 2009]. Storytelling opens the door for sophisticated connections to Native American cultural heritage as we have seen in the dual use of ceremony and technology in Galindo's Indian Summer -- and could address concerns stated by groups like the Forgotten People who believe Native environmental justice rests on the successful integration of Diné hozhó beliefs. Asset mapping, a more formal version of the storytelling approach that can help to document material resources, stakeholder interests, and institutional support, could provide

additional insights into factors that could potentially impact a culturally situated sensing project [McKnight and Kretzmann 1996].

A second apparent connection to Navajo traditions can be made to technical appropriation and peer-produced adaptations. Skills associated with crafts such as rug weaving, basket making, and beadwork, are highly valued and pass generationally -- evolving according to the aesthetics of the individual maker and availability of local materials [Bennett 1997]. Navajo communities may therefore be well attuned to participatory models of technical skill sharing regularly practiced in user innovation and DIY initiatives. Projects stemming from the vast hybrid open-source/proprietary market could therefore provide useful insights for Native American citizen science. Utilizing readily available sensor technologies, for example, might begin with the process of collaboratively building local technical skills as was done in Leah Buechley's Lilypad studies. Or placing greater degrees of control in the collection and interpretation of data as anticipated in projects like Grassroots Mapping might then provide opportunities to co-create Asthmapolis-like systems for Navajo-specific use.

Third, and perhaps most important, the exploration of informational/material and proprietary/non-proprietary community based research matches well with the Navajo experience, accustomed to negotiating complex institutional, historical, and cultural partnerships [Hernandez et al. 2001]. The larger take-away of these combinations should make clear the potential for developing influential hybrid arrangements on many levels: by leveraging the power shifting effects of alternative social movements, in the recognition of local as well as external knowledge and expertise, and through the free appropriation of technologies for citizen science campaigns. Where each of these has shown mixed

capability for scaling up their success into broader movements, a combination approach may do just that.

The Black Mesa Water Coalition's Green Jobs program --hailed as a "miracle" by veteran Native activists – succeeded where others had failed by resourcefully mobilizing the cultural bonds of Diné Natural Law and by tapping into a growing Navajo movement looking to restore environmental balance for future generations. What additional challenges might we overcome through the useful applications of culturally situated sensing? Discovering optimal solutions would be daunting for a small community of activists working independently, but the same could be said of an externally working research or design team -- each uninformed by the absence of the other. Therefore the process of culturally situated sensing must begin by grounding the project as an act of co-producing cultural, environmental, and scientific identity. It is the hope of this author that the catalog of theoretical frameworks and case studies detailed herein might illustrate pathways through which this process might take shape.

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