Local Issues, Local Uses: Tools for Robotics and Sensing in Community Contexts

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ABSTRACT
This paper describes six creativity support tools we developed to foster community engagement and expression with robotics and sensing, assessing the benefits and shortcomings of each tool. From the descriptions of these tools and their uses, we highlight two issues. The first is the challenge of, and a general strategy for, enabling informed speculation with unfamiliar technologies. The second issue is that in enabling such speculation, the research process is opened to significant shifts in trajectory. These shifts concomitantly serve as markers of technological fluency and challenge the research project, reinforcing the value of a community co-design approach.

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H.5 Information Systems. H5.m. Miscellaneous.

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INTRODUCTION
Once solely the province of academic, industrial and military scientists and engineers, robotics and sensing technologies are increasingly being used in commercial products and systems. But research on how such technologies might be used by non-experts in everyday settings is still nascent. Such research is important for advancing a democratic approach to technology design [5,24,34,39,42], and too, can be influential in shaping future research and development agendas. [12,24]

The notion of engaging with individuals and groups through participatory design and cooperative inquiry to explore the possibilities of technology is well established. However, enabling the inventive application of sensing and robotics to local issues and conditions by non-experts presents several significant challenges. Foremost among these is that, unlike information and communication technologies (ICTs), which are pervasive in everyday life and the subject of much cultural attention, robotics and sensing technologies are unfamiliar. Except in their most spectacular forms, robotics and sensing technologies are often seamlessly folded into existing products and the environment and therefore rarely directly engaged by the public.

In this paper we present and reflectively assess a set of creativity support tools we developed to facilitate engagement with robotics and sensing technologies in the context of participatory design/co-operative inquiry programs. The goal of these programs was to enable neighborhood residents who had no design, engineering or computer science background to develop a level of technological fluency such that they could design, in an informed manner, new products, services and systems that employ robotics and sensing technologies to communicate or address local issues and conditions. Our challenge then was to develop tools in order to:

- Familiarize our participants with the capabilities and limitations of robotics and sensing technologies
- Connect these technologies to local issues and conditions
- Enable the speculative, but informed, design of robotic and sensing products and services situated within their neighborhood

We begin this paper by reviewing related work, which influences our research. We then present an overview of the context for which we developed these tools, describing our research objectives and the program structure. Following that, we discuss the six tools developed: *Neighborhood Sensor Walks, Canary Test Kits, Collage in Context, Robot Storyboarding, Concept Mock-Ups,* and *System Mapping*. Finally, in the discussion we address two issues. The first is a general strategy for enabling informed

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speculation. The second issue is that in enabling such speculation, the research process is opened to significant shifts in trajectory. These shifts concomitantly serve as markers of technological fluency and challenge the research project, reinforcing the value of a community co-design approach.

RELATED WORK

Our work is influenced by scholarship and practice in ubiquitous computing [9,11,13,31,39], design and the arts [5,15,16,27,33,34,40], cognitive science [36, 41] and education. [6,8,22] Within the arts, participatory sensing activities focused on issues of engagement and the rhetorical capacity of creative and critical public technology events have had particular significance in shaping our work. For example, the *Feral Robot Dogs* project developed by Natalie Jeremijenko used inexpensive toy robot dogs, outfitted with wheels and sensors, as mobile pollution detectors. [29] Working in cooperation with neighborhood residents, these robot dogs were released in packs to "sniff-out" pollution in selected areas. A central aspect of the *Feral Robot Dogs* project was what Jeremijenko refers to as its 'mediagenic' quality: how the event of neighborhood residents releasing robots into the environment would consistently garner media attention, thereby initiating a new dialogue about neighborhood conditions. This inspired us to consider how community co-design programs might function as a kind of public rhetoric, enabling new forms of argument, expressing and advancing alternative perspectives on neighborhood issues. [14] *Tripwire* was a public sensing project designed by Tad Hirsch for the 2006 San Jose 01 Biennale. [26] Using audio sensors connected to mobile phones (encased in coconuts) Hirsch installed a sensing network in the neighborhood surrounding the San Jose airport to monitor audio pollution produced by planes flying overhead. When the sensors detected sound above a given threshold, they would automatically call the City of San Jose noise complaint line, registering an (often humorous) complaint. Although *Tripwire* does not directly involve residents of the neighborhood, it is an example of the kind inventive sensing product and service grounded in a neighborhood issue we hoped our program would incite from our participants. Finally, the *AIR* project by the Preemptive Media collective enabled non-experts to use a custom hand-held air quality monitor to explore and document urban neighborhoods. [40] Aspects of this project are identical to ours, with a key difference being our focus on research and the desire for participants to use the monitoring process as a basis for ongoing design.

Research in participatory design and design studies has also significantly influenced our project, highlighting the challenges of enabling informed speculation and reframing the practices and objectives of design. Approaches such as playful triggers [35] and the use of games [7] provide novel and compelling methods for sparking imagination and discussion with participants. But, as Büscher, et. al have discussed, to be productive, imagination must often be coupled with a grounding in life conditions and technological capabilities. [10] Recently, scholars in design have suggested new modes of practice, ranging from critical design [15] to the notion of participatory design as the practice of enabling participation in the construction of "dangerous things" [16] that is, public assemblages of people, issues and technologies with political identities and desires. These new modes of practice bring the discursive elements of design process and products to the fore, as they strive to raise issues and provide prompts for debate.

Finally, our work is influenced by research on creativity, in particular from the vantage of education and cognitive science. This research has yielded a richer understanding of the processes that support individual and group creativity [2,37,49,52], which in turn has enabled the design of increasingly more sophisticated tools and socio-technical environments to support social creativity. [1,23,47,48,49] Within this research an emerging theme salient to our work is the design and evaluation of computationally-based creativity support tools in both general and specific collaborative problem-solving domains. [19,46,47,51] Our work finds common ground with these computer supported collaborative learning (CSCL) perspectives on social creativity and draws inspiration for the use of sensing and robotic technologies both as creativity support tools and as systems for creatively addressing social and environmental issues in the community.

SETTING THE CONTEXT: THE NEIGHBORHOOD NETWORKS PROJECT

The tools presented in this paper were developed as part of the Neighborhood Networks project, which is a strand of research within a larger project entitled The City as Learning Lab (CaLL). Most broadly, our research asks: How can the city can be "activated" as a distinctive environment for learning about robotics and sensing technologies, and too, how can robotics and sensing technologies be used as platforms for distinctive modes of learning about the city. The learning that we are interested in is different from the familiar objectives of technology education programs. Our concern is not the learning of technological content and engineering design processes alone. Our concern is the development of technological fluency in our participants. [4] Furthermore, our programs strive to direct this fluency towards social ends: so that the participants can employ robotics and sensing in the creative and critical expression of identity; discovery and articulation of local issues of concern; and conceptualization and communication of possible interventions into these local issues of concern. As markers of technological fluency, we look to group processes that demonstrate social creativity around robotic and sensing technologies and the facility to imagine and translate non-technical goals into technological solutions. Central to our work then is the goal of understanding the kinds of tools and conditions needed to support the growth of technology fluency.

Primary Themes of the Neighborhood Networks Project

Although each neighborhood that participates in the Neighborhood Networks project brings its own history, social arrangements, needs and desires to the project, thereby producing a distinct form to each engagement, there are three organizing themes that structure the Neighborhood Networks projects. These are **1) the use of design-based activities, 2) grounded in local conditions, to foster 3) critical and creative engagements with robotics and sensing technology**. It is these themes that motivated and directed the design of the tools we have developed for engaging communities with robotics and sensing technologies So, we will briefly describe these themes here, and then further develop them, by example, throughout this paper.

Our activities were **design-based,** in that they drew from practices in interaction design and participatory design that have been developed to support the conception, planning and production of products and services, as well as the use of design towards the development of case studies and theory. We refer to our activities as design-based in reference to and acknowledgment of our own position as designers, design researchers and education researchers working with and through design. As such, they share features with approaches to design-based research that span the learning sciences [3], design studies [18], and human-computer interaction. [17]

Our program, and the activities that constituted the program, were **grounded in local conditions**: they were designed to facilitate connecting robotics and sensing to the neighborhood environment and issues. Our conceptualization of the environment was broad and sought to surface relationships between the material qualities and the social structures of the neighborhood. Our emphasis in grounding the program and activities in local conditions was motivated by both technical and pedagogical agendas. From a technical perspective, we wanted our participants to explore the ways in which sensing and robotics might *specifically* monitor and act on/in their neighborhood, and achieving this specificity of coupling between the technologies and the neighborhood required attention to local conditions. From a pedagogical perspective, we wanted to develop a program that exhibited "thick authenticity" [45]: that was germane to the issues of a given neighborhood, respected that neighborhood, and explored a plurality of applications that would only come about by emphasizing the distinctiveness of each neighborhood we engaged.

By **critical and creative engagements** with robotics and sensing technologies we mean experiences that bring about the analysis and interpretation of issues, building from traditions in education [6,22], design [15,16] and the arts. [28,30,33] From the perspective of the critical, our goal is to provide people with experiential knowledge so that they can make informed and insightful suppositions and judgments concerning the capabilities, limitations and applications of technology. From these critical engagements we hope to facilitate creative expressions, by which we mean imaginative and resourceful representations of problems, or possible interventions into the conditions of a problem. Our goal is not to teach people to be engineers, but rather to help bring people to a point of technological fluency where they are comfortable with and capable of utilizing the products of engineering beyond familiar uses. Regarding the use of technology then, our interest is how people apply and manipulate a given technology while infusing the artifacts or systems they produce with their own voice and style.

Project Description and Methods

Between 2007 and 2009 we engaged two neighborhoods in Neighborhood Networks programs. In the first neighborhood, the program ran for 8 weeks and included approximately 14 neighborhood residents as active participants, ranging in age from early teens to mid-60s. In the second neighborhood, we ran two programs. The first program ran for 8 weeks and included 8 neighborhood residents as active participants, all of who were aged 12-18. The second program ran for 9 months (with a 1 month winter holiday break) and included 9-12 regular participants, all of them adults. In this second program, approximately 3/4ths of the participants were residents and the other 1/4th were leaders of neighborhood organizations, but did not live in the neighborhood.

The discussions of the tools in this paper are based on observations, field notes, and informal communications collected over the span of the programs. Two to four researchers were present at each event. Throughout the events, researchers took field notes documenting the participants' interactions with the tools and additional field notes were written after each event. Informal communication regularly occurred between at least one of the researchers and participants, through email or phone calls, providing another source of feedback and insight on the program as it progressed. Taken together, these field notes and communications provided a thorough overview of the activities and tool usage and enabled the descriptions and reflective assessments that follow.

TOOLS

In the following sections we describe and assess six creativity support tools and the associated design activities we developed to enable critical engagement and creative expression with robotics and sensing technologies. The first set of tools **familiarized** participants with the capabilities and limitations of robotics and sensing technologies. The second set of tools explored the potential of these technologies to **connect** with local issues and conditions of concern or interest. The last set of tools **encouraged the speculative, but informed, design** of robotic and sensing products and services situated within neighborhood.

A. Tools for Familiarizing

The first set of tools were designed to familiarize participants with the basic capabilities and limitations of robotics and sensing technologies and provide vocabulary around which to imagine, describe and critique how these technologies might serve the neighborhood. To facilitate this we used a simple prototyping device called the Canary. The Canary is a handheld robotics and sensing platform capable of monitoring a suite of environmental factors including air quality, humidity, temperature, sound, and light levels. Each of these sensor inputs can be connected to servomotors to create interactive devices that respond to one or more of the sensed conditions, without any programming.

Tool 1. Neighborhood Sensor Walk

Imagining the practical application of unfamiliar technologies to familiar environments is a challenge. Preconceived notions of robotics and design make initial discussions around the use of these technologies in the neighborhood difficult. To support informed participation and reach our project goals of increasing technological fluency in the group, it was important to provide participants with experiential knowledge around the possibilities of simple sensors coupled to reactive mechanisms. The Neighborhood Sensor Walk was designed to help participants become familiar with the technology as quickly and easily as possible and ease the transition from unfamiliar to familiar, by enabling participants to explore sensing technologies (using the Canary) and their affordances within the context of their own neighborhood

Description of Tool and Use

The Neighborhood Sensor Walks were run in multiple neighborhoods and each Sensor Walk followed the same basic format. A large printed map of the neighborhood was placed on a table along with Canaries, Polaroid cameras, and two sets of prompt cards to help direct participants' explorations. One set of cards prompted participants to find sensory extremes (lightest vs. darkest, loudest vs. quietest) and the other set prompted picture-taking of neighborhood characteristics (historical features, evidence of neighborhood personality, or evidence of change). The prompt cards encouraged participants to use the Canary to measure unfamiliar data within familiar settings, such as the humidity of a library ceramics studio, the air quality in a basement bar, and the light levels in side alleyways. As participants returned from their Sensor Walk they attached their photos and prompt cards to the large neighborhood map, and discussed their findings and ideas for other kinds of information that could be discovered. In this way the map became a visualization of the Neighborhood Sensor Walk experiences, generating conversation about the findings and speculation about other locations and conditions within the neighborhood.

Benefits and Shortcomings

The primary benefit of The Neighborhood Sensor Walks was to get the participants out and about and sensing in their neighborhood. Through this experience participants encountered the basic capabilities and limitations of the Canary as a specific platform, and of sensing technologies more generally. For example, participants were surprised by, but quickly discerned, what could and could not be sensed by the Canary: whereas the exhaust from a car might register on the air quality sensor, the stench of a portable toilet would not. In discussing why this was so, the participants began to develop an awareness of how the technology functioned and how this functioning did or did not relate to their experience, e.g., the air quality sensor measured CO, not "smells" — something could smell bad but not be able to be measured by this, or perhaps even other, sensors. Participants also experienced the frailty and ambiguity inherent in sensing technologies. For example, participants would stand on a street corner hoping to detect changes in air quality due to traffic. After some experimentation with where they were standing, they would determine that in fact they had to be both very close to the traffic and downwind for the sensor to register. Through such experiences participants began to develop tacit knowledge of sensing as an activity and sensors as specific technologies.

Once comfortable with how the Canary functioned, participants related the technology and data to the common neighborhood themes. For example, in one neighborhood known for its poor air quality and high asthma rates, participants were particularly drawn to the air quality sensor and its potential for identifying sources of pollution. Making such associations between the sensing technology and the environment and identity of a neighborhood is the kind of familiarizing engagements we hoped to prompt, in order to provide the basis for later activities in which participants would more directly connect the sensing technologies to specific places and phenomena in the neighborhood.

The final benefit of the walks came from the public nature of the activity. By taking place outdoors in a central location, the walks generated curiosity from passersby and helped spread awareness of our project at a very early point in the process. However, we should note this curiosity also turned out to be the one significant shortcoming of the activity: those who were introduced to the technologies incidentally, i.e., by encountering the participants engaged in the sensing, were less able to generate functional knowledge and place-based conversation and tended to focus solely on the novelty of the technology. For example, in reference to the Canary we heard "I really like these kinds of things" or "cool device" but these comments did not necessarily connect to local conditions or ideas for relevant applications.

Tool 2. Canary Test Kit

The Canary is not only a tool for measuring sensed data; it is also a platform upon which people can design expressive and interactive robotic devices. Because our participants tended to be adults with little hands-on design and technology experience, we knew they would need to become familiar not only with the technology itself but with using it as a tool for creative expression. The Canary was intended to expose participants to creative sensor use, so we constructed a kit for testing the Canary's capabilities and visualizing those measurements in a playful manner.

Description of Tool and Use

The test kit consisted of a brown paper bag containing an assortment of materials to trigger the various sensors, including: alcohol-based pens, candles and matches, eyeglass cleaner, noisemakers, and flashlights. The kit also included a paper template for a generic gauge to visualize sensor measurements. The participants could use markers and small crafts objects like pipe cleaners and plastic flowers to customize the gauge and then, by attaching the gauge to the Canary with a servomotor, the gauge would respond to a triggered sensor.

The activity consisted of three stages. First, participants explored the Canaries' sensing capabilities with the provided triggers. Second, participants created gauges to display sensor readings. Third, participants were asked to discuss how the visualizations might effectively address local issues. This final step elicited the ideas of creating a robotic device to monitor a local bridge undergoing major rehabilitation and constructing a coughing robot to measure air pollution.

Benefits and Shortcomings

The test kit greatly benefited those participants who were not used to tinkering with sensor and simple motor assemblages. By providing tools and a structured activity within which to use them, participants appeared to feel more at ease testing, discussing and creating on their own interactive sensing devices and the open-ended, exploratory nature of the activity allowed for the process to be mostly participant led. The self-directed pacing allowed time for participants to become familiar with these technologies and begin to find relevance and application for them in the neighborhood. For example, in one workshop two retirees spent most of their time experimenting with various materials in the test kit, while two others worked together to make the gauge 'accurate,' while yet another participant worked individually to list the places in the neighborhood where these sensors might be useful.

B. Tools for Connecting

In addition to familiarizing participants with robotic and sensing technologies, we hoped to guide them in creating novel and appropriate design solutions that creatively engaged with the issues at hand. Building on the Neighborhood Sensor Walks, we aimed to develop critical engagements with the technologies to creatively connect them to local conditions and issues of interest and concern. The next two tools were designed to provide participants with opportunities to think about where and how the technologies might be meaningfully applied in the neighborhood.

Tool 3. Collage in Context

In order for people to think critically about how the capabilities of environmental sensors might intersect with their own community issues, they must make the connection between data sources, what that that data means for their local community, and how they might act upon, or with, that data. The Collage in Context tool was developed to prompt connections focused on opportunities of localized data monitoring. In what follows, we present the tool as it was used in a specific workshop, in which participants identified two problem areas in the community: the neighborhood's poor air quality and the traffic congestion caused by a nearby bridge rehabilitation. To determine how the sensor technologies might address the problem areas, the participants were asked to place an image of the Canary in specific locations and define the data the Canary would measure in that particular location.

Description of Tool Design and Use

We constructed collage kits for the two problem areas the group had identified. Collage kits are common tools in participatory design practices—they allow participants to generate and express ideas around a topic through a given set of words, images, and parameters. Each collage kit contained 8.5 x 11" photos of the local context; thumbnail images of the Canary; and glue sticks, scissors, pens, and paper. The participants divided into two groups, one focusing on air quality and the other on traffic monitoring. Through a collaborative process of speculation, discussion, and evaluation, each group pasted the Canary images onto the photos, connecting the sensing technology to the local environment.

Benefits and Shortcomings

By maintaining appropriateness to local conditions, participants were able to address the issues directly and creatively. For example, one participant used the collage kit to show how the Canary might monitor traffic on the main street in the neighborhood, triggering an alert system when speeds are too high. The alert system – a song recorded by members of a nearby church choir – would play over loudspeakers. This novel idea led to the approach of broadcasting the song over a radio station instead of loudspeakers, which, in turn, developed into the design solution of a local radio station that monitors traffic.

The collage activity had one notable shortcoming: it was predominantly speculative, based solely on the participants' existing knowledge rather than actual data. Had the participants captured actual data by taking the Canary out to the specified points of interest, they could have produced collages more grounded in the capabilities of the sensors and technologies in those actual conditions.

Tool 4. Robot Storyboarding

Scaffolding both robotics content and the design process was necessary in order for participants to produce descriptions of how a robot intended for use in their neighborhood would work. To address this challenge, we developed robot storyboards. Through the activity of storyboarding participants attempted to make their ideas explicit by producing sketches and descriptions of the parts, construction, interaction and purpose of their robots. A key quality of storyboards is that they do the work of both an elicitation and documentation device: they draw out the desires and intentions of the participants, couple these with perceived technical capabilities and limitations, and provide reference for ongoing design activities.

Description of Tool Design and Use

We needed a structure that would support the design process of specifying intended use while also reinforcing a basic knowledge of robotics and sensing technologies. To support this, we developed a set of custom storyboards, which asked questions organized around four themes:

- Actions: What actions will people, things or the environment take that affect the robot?
- Sensing: What does your robot sense from those actions and using what sensors?
- Output: How does your robot react to those actions and express what it senses?
- Communication: What do you want to communicate through your robot? How should people feel or respond to your robot?

Benefits and Shortcomings

The main benefit of the storyboards is that they prompt participants to think more completely though a situated scenario of use, and in the process, to develop associations between intention, use, capabilities, and requirements. For example, one participant developed a concept she called "Fans of Fury." She began with the theme of Communication and created something that people would find visually appealing. From this she progressively built out the notions of Actions, Sensing, and Output, eventually tying the motion of the fans to the action of clearing pollution by spinning "furiously." The final concept was one of large colorful fans strung on a cable across a busy intersection: as the pollution levels rose, the fans would spin, lowering the pollution, and in the process, making passersby aware of environmental conditions.

As a method of expression, writing was more actively pursued than drawing. All participants wrote at least a few sentences in response to each of the questions. One might argue that given this predisposition to writing, we should emphasize writing over drawing in the design of the tool. However, we believe that drawing is an important aspect of the process precisely because it removes people from their rote practices and connects them to designerly and artistic practices and modes of knowledge production.

C. Tools for Speculating

The next set of tools we developed were intended to encourage informed speculation and reflection on design situations involving sensing and robots in the neighborhood. By informed speculation, we mean that a diverse group of non-experts in robotics had enough functional knowledge about sensors and simple actuators to survey and define a landscape of possibilities for how these technologies might be used productively in the neighborhood to address issues of concern. In the next section we describe how Concept Mock-Ups and System Mapping tools facilitated informed speculation and critical engagements around the community identified issues (air quality, traffic congestion and safety, community information access). We also describe how these creativity support tools functioned to help the group imagine and plan robotic services and interventions for the neighborhood.

Tool 5. Concept Mock-Ups

Work in creativity support tools has shown the value of "externalization" artifacts to facilitate and communicate a collective idea. [8,19,41,50] Through prior engagements with our tools, participants had developed a shared verbal language and a set of experiences around which to describe project ideas, but they had yet to collaboratively produce a representation or externalization of the group concepts. To prompt collaborative creative exploration and foster a community of learners [44], we encouraged participants to co-create an artifact that articulated and embodied the group's ideas for how interactively enabled sensors could be used to serve the neighborhood. To support a creative externalization process, we devoted two workshop sessions to the creation of Concept Mock-Ups—presentation artifacts that would be used to communicate to community residents in weeks to come. This activity had the dual purpose of getting participants to collectively articulate and refine their individual ideas into a shared concept while also preparing them to present their concept to an external audience.

Description of Tool Design and Use

Our participants clustered into two self-selected groups based on affinity and interest. Each group pursued different representational techniques to externalize their design ideas. One group choose to mock-up an Air Quality Gauge, a deployable unit to monitor air quality in critical locations around the neighborhood. This group made a poster using a tri-fold presentation board with a focus on size, color and iconic representation in order to attract interest from passersby on the street. The group, drawing on the familiar fire-risk standards, created a color-coded scale in green, orange and red sectors to represent local air quality conditions ranging from good to fair to poor. They then took the gauge one step further and added literal representations of poor air quality (and drawing from the name of the technology platform – the Canary) as a caged canary keeling over and a baby with a gas mask. The group decided to add a servo-controlled canary that would tip and eventually fall off its perch when air quality conditions were poor. As they worked on their presentation, the activity surfaced potential problems in weather and vandal proofing, storage and gauge placement in the neighborhood. As a mild form of protest, one participant suggested placing the gauge out in front of the library to notify offending bus drivers who exceeded the five-minute idling limit ordinance.

The second group, in response to a major rehabilitation project on an already congested bridge, decided to purse the idea of a locally run community broadcast system that monitored traffic conditions and provided community news, events and entertainment segments. To illustrate the concept, the group fashioned a three-dimensional model of the local area: blue tissue paper became the Monongahela River, modeling clay was sculpted into cars and trucks, and pipe cleaners were used to represent the broadcast antennae, roadways and bridges. Sticky notes were used to envision a preliminary signage system notifying drivers and residents about the new radio station. The model also prompted discussion about how to enable cell phone users to contribute audio comments and feedback to the station.

Benefits and Shortcomings

One benefit derived from the Concept Mock-Ups was that color selection, paper cutting and gluing activities surfaced new discussions about signifiers, scale, size and placement of the system components within the design. For example, when constructing the bridge surface black pipe cleaners were used to indicate four lanes of traffic. One participant mentioned that lane closures would significantly affect traffic flow and change where the traffic monitoring sensors should be placed. The group then chose to use a red pipe cleaner to indicate a lane closure and moved the traffic sensors accordingly.

The activity also allowed visual solutions to emerge before requiring participants to apply language and explain their ideas in words. We noticed that quieter members of the group had an alternative means by which to contribute their ideas. The flow of discussion and activity around the table allowed the group to integrate and synthesize each other's ideas together in real time.

Another benefit of creating these externalized representations is the "back-talk" of the design. [46] In building the mock-up of the traffic-monitoring broadcast, it became clear that the range of the broadcast would significantly affect the placement of the traffic monitors. The group recognized that they might have to scale down the monitoring service and focus their attention on commuter rather than neighborhood audiences.

While the process of creating low-fidelity mock-ups supported a creative internal group process, it was less successful in creating a presentation artifact to use with external audiences. Our participants were, by and large, senior level administers of organizations within the community. While they enjoyed producing the Concept Mock-Ups, they seemed reluctant to take them seriously as communication tools, perhaps concerned that the unpolished qualities might not be a suitable form of expression. And yet, when the mock-ups were displayed on tables at a community event, their unfinished qualities seemed to invite the community's comments and critiques of the project ideas.

Tool 6. System Mapping

Through the series of participatory design activities described above, the participants came to an easy consensus that as a project concept, the community radio broadcast linked to data about traffic conditions and air quality would best address their collective concerns for improving conditions in the neighborhood. The next tool was designed to elicit how the various elements of the broadcast system would work together in more detail. In particular we wanted to support informed speculation around how the traffic and air quality sensors would be linked to the radio broadcast and affect the programming content users would hear. We also wanted participants to consider how the immediate practical constraints of the available technology would inform their proposed design.

In the System Mapping activity, we asked participants to indicate where air quality, traffic monitor, and sound sensors should be located in the neighborhood. To do this, they placed color-coded stickers on a large format map and cut out a colored transparency overlay outlining the anticipated broadcast coverage area. With the infrastructure of the system laid out, participants formed into small groups to fill out a programming schedule for broadcasts, based on relevant sensor readings. This activity was done twice: the first time designing the system around the actual transmitter and sensors we tested, and the second time designing the system around an unconstrained broadcast range and unlimited sensor accuracy.

Description of Tool Design and Use

Not surprisingly, participants showed an affinity towards the technology most salient to their primary issue of concern. A participant who had taken over responsibility for the antennae took charge of determining where the transmitter should be placed. The two participants who expressed the most concern around pollution issues worked together to place air quality sensors on the map in six locations they considered vital to monitor. The executive director of the library, frustrated with noise and unruly after school activity, placed two sound sensors on the map: one in front of the library and one next to the basketball courts across the street.

As participants gathered into small groups to plan a programming playlist, each group recognized that, given the hyper-local broadcast range, the radio audience would be limited to bridge on-ramps and the bridge crossing itself. Each group independently decided to use the traffic monitoring sensors, which detect average car speed, as a trigger for selecting the types and length of programming content to play. One group calculated that during off peak hours the access to the broadcast would be 15-30 seconds; during peak congestion access to the broadcast could be 5-10 minutes. For congested traffic, groups planned for segments with a longer playtime-–traffic updates, sound bites of local interest, news or calendar events to be selected.

Benefits and Shortcomings

This engagement demonstrated how changing specific technology constraints directly affected how the participants conceived of using the sensors. In the hyper-local broadcast scenario, the participants' programming ideas were highly dependent on the traffic sensor readings and the inferences that could be made about the type and length of programming content that would be appropriate for commuters. The unconstrained broadcast scenario allowed for longer-format programming ideas and a more community-centered audience with the use of real-time traffic sensor data as a trigger for programming a standard traffic report.

DISCUSSION

Upon reflection, enabling informed speculation has emerged as the central challenge of the Neighborhood Networks programs, with relevance to related community robotics and participatory sensing programs. The crux of this challenge is maintaining a balance between structured activities that convey and reinforce the limitations and capabilities of a given technology, and open activities that not only allow for, but also prompt imaginative thinking within an unfamiliar technology.

Many of our tools shared a strategy of requiring participants to maintain this balance within a single activity. So, rather than separating learning and application, the endeavor of discovery and synthesis occurred together within a single activity, often in a tight feedback loop. For example, in the Robot Storyboarding, participants were required in a single activity, and in a single representational form, to imagine the ends to which they wanted to apply robotics and sensing, and then specify how the robotics and sensing technologies available to them could achieve these ends. This often resulted in an iterative process of proposing function, evaluating that function against the known capabilities and limitations of the technology, then refining the proposal. One benefit of this strategy is that participants began thinking about the application of the technology in an experientially informed manner from the beginning. Another benefit this strategy had was a cumulative effect. As the programs progressed, participants were able to iterate on concepts or incorporate aspects of early designs into later designs. For example, in the System Mapping activity for the sensor-linked community radio broadcast, participants chose to add three sound sensors to the map to monitor activity along a particular street of concern. This notion of sound acting as an early warning indicator of potentially disruptive nighttime behavior was first discussed during the Canary Sensor Walk activity.

Keeping the activities open and allowing for speculation had another, unexpected effect: *it enabled participants to veer away from the charge of designing systems in which robotics and sensing were central, to instead imagine, invent and design for the use of these technologies as supporting elements in other kinds of systems*. In this way, the tools prompted and supported the kind of critical and creative engagement and technological fluency our program was striving for: demonstrating social creativity around robotic and sensing technologies that extended our ideas and intentions, and aligned to the participants' interests and desires.

The prime example of this is found in the community radio concept. Through the tools, activities and accompanying discussions, that group discovered and articulated a shared desire to communicate the unique qualities and issues of their neighborhood to others. On their own, quite surprisingly to the research team, they decided that a community radio broadcast would best suit this desire. In this design, sensors were then cast as a novel means of both collecting information about the neighborhood and controlling the program. The group went on to explore ways to use the sensors to deliver programming that was selected and timed based on sensed traffic speeds and the inferred commute conditions.

It is important to note that this fluency in the use of robotics and sensing in the creative expression of identity and the application of technology to non-technical goals, in fact presented a challenge to our research and the trajectory of the project: we were not community radio experts. To accommodate this design direction required then that we explore and learn about radio broadcast and production together with the participants, invite in new expertise and fold in new technologies to the ongoing program. Such dynamic research situations reinforce the value of a community co-design approach.

Community Co-Design

A distinguishing feature of our community-based work with sensing and robotic technologies is our approach to the design process. Our programs are deeply to committed to close participatory design work with community residents from the inception of program implementation. We take the explicit stance that all participants in the group are co-designers who bring diverse expertise and skills to the creative process. The researcher, who may be a designer, then takes on the role of a facilitator. [43] True community co-design work leverages collective creativity to imagine and plan technology-enhanced actions, interventions and services based on internally-sourced issues and interests. Such an approach is necessary to maintain the flexibility and adaptability required to respond to expressed desires of a given community.

In future work, we would like to push this co-design process further to include participants in explicit and ongoing forms of participatory evaluation during the course of the design process. One advocate of more democratic evaluation methods espouses a "process-generated evaluation" approach that involves all stakeholders and allows for a negotiated form of evaluation that emerges from the group. [25] Such methods allow goal-setting criteria for success and stopping points to be consensually determined by the group.

CONCLUSION

The 2003 National Research Council report *Beyond productivity: Information technology, innovation and creative IT* [38] makes the case that information communication technologies (ITC) are opening new creative arenas. Moreover, tools for such creativity with technology are becoming more open and accessible, offering new trajectories and practices of participatory culture. [27] We would argue that as sensing and robotics become more mainstream, they will have the same potential to support creative and participatory socio-technical environments. They will also require tailored sets of creativity support tools to enable a broader range of citizens to use these technologies to creatively engage in problem solving and take action on social and environmental issues.

Media affects the nature of learning and communication in the design process. Much of the creativity support tool work to date has focused on communication interfaces that are screen based. Our work seeks to develop a set of tools to foster creative and critical engagements that enable everyday citizens to engage in meaning making with sensed data from their local environments.

We believe that with creativity support tools such as those we have presented in this paper, everyday citizens and non-experts can begin to critically and creatively engage with these technologies for positive social ends. Low-cost, reliable and easy-to-use sensors put the persuasive quality of scientific data in the hands of citizens. Moreover, robotic technologies themselves can become a powerful communication and expression form that is mobile, embodied and interactive – in other words a form of new media. To weave sensing and robotics into participatory culture, as has been done with other media, requires new tools, and too, new approaches to research. In enabling informed speculation, the research process must be open to significant shifts in trajectory, as such shifts exemplify the very moments of technological fluency sought after.

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