Sensr: Evaluating A Flexible Framework for Authoring Mobile Data-Collection Tools for Citizen Science

Sunyoung Kim[1] **Jennifer Mankoff**[1] **Eric Paulos**[2]

[1]Human-computer Interaction Institute
Carnegie Mellon University
5000 Forbes Avenue, Pittsburgh, PA
{Sunyoung.kim, jmankoff}@cs.cmu.edu

[2]Electrical Engineering and Computer Sciences
University of California, Berkeley
Berkeley, CA 97420-1776
paulos@berkeley.edu

ABSTRACT

Across HCI and social computing platforms, mobile applications that support citizen science, empowering non-experts to explore, collect, and share data have emerged. While many of these efforts have been successful, it remains difficult to create citizen science applications without extensive programming expertise. To address this concern, we present Sensr, an authoring environment that enables people without programming skills to build mobile data collection and management tools for citizen science. We demonstrate how Sensr allows people without technical skills to create mobile applications. Findings from our case study demonstrate that our system successfully overcomes technical constraints and provides a simple way to create mobile data collection tools.

Author Keywords

Citizen science, mobile applications, sustainability.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

General Terms

Design

INTRODUCTION

Citizen science has a long history beginning as early as a century ago by the Audubon Society. They started the Christmas Bird Count, asking volunteers to count the number of bird species they observed during the winter holidays [24]. Since then, citizens' efforts to collect data for scientific work have been a great resource across a variety of domains.

There are currently over 15 million citizens watching or recording birds in the United States [3], and over 4,200 conservation organizations are listed in the National Wildlife Federation [25]. The domains to entail public participation become varied from traditional ecology and environmental conservation [37,7] to greater diversity including but not limited to astronomy [31], biology [10], archeology [40], and community monitoring [2].

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This growth is facilitated by the increasing affordability, availability, and adoption rates of Internet-enabled and location-aware mobile devices. The Pew Internet Project reported that nearly half of all American adults (45%) and two-third of all young adults (66%) now own a smartphone as of Sep 2012 [36]. The proliferation of mobile computing technologies is making our urban environments rich in terms of sensing, providing diverse channels to scientists for data collection, and creating tremendous opportunities for everyday people to engage in scientific projects [16].

As such, mobile devices are well suited for spontaneous data collection by everyday people. However, under its guise of simplicity lies technical expertise and complex infrastructure. As a result, building such applications is a large investment that may limit smaller organizations.

Sensr, the primary contribution of this work, is an authoring tool that enables non-programmers to create mobile data collection tools for citizen science. It leverages the fact that the process and structure of data collection activities in citizen science are similar across domains despite their diversity [5]. Sensr combines a visual programing environment with a mobile application where people with limited technical expertise can build mobile data collection tools and manage data collectively. As illustrated in Figure 1, people seeking data can author a citizen science campaign on the Sensr website. The campaign is then deployed on the mobile Sensr application, and users of the mobile Sensr app can subscribe and contribute data to the campaign. Sensr radically simplifies the entire process of creating a mobile data collection tool for a wide range of citizen science domains. Authors only need to fill out a project description and design data-entry forms before launching their campaign within the mobile Sensr application for wide distribution. This frees authors from worrying about technical requirements and infrastructure constraints.

A secondary contribution of this paper is the analysis of design considerations for citizen science projects through a literature review and examination of online data about

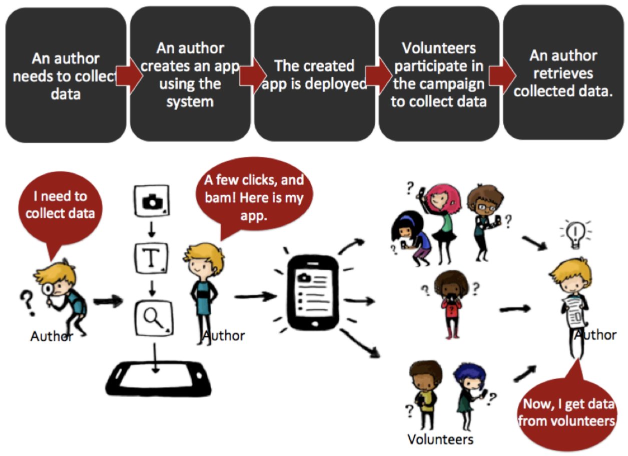

Figure 1. The process of using *Sensr*: an author creates a campaign → the created campaign is deployed on the mobile application → volunteers subscribe and collect data in the application → collected data is sent back to the author

existing digital citizen science projects, including both the authoring and volunteer experience. We discuss the current state of citizen science, particularly the use of mobile and computing technologies, and the roadblocks that inhibit digital citizen science's growth in order to develop design considerations to apply to Sensr as well as a reference for future citizen science research.

Our case study validates that authors without technical skills, in three separate organizations, successfully used Sensr to author mobile applications. Additionally, the study highlights real-world authoring issues such as translating existing campaigns into mobile-friendly reporting interfaces and the unexpected use of collected data.

Overview of Paper

We first provide our trend analysis of technology use in contemporary citizen science to elicit design considerations for digital citizen science. After explaining Sensr in detail, we employ a case study in which preexisting citizen science projects use our system. Finally, we discuss the implications this work has on the design of citizen science authoring technologies.

DESIGN CONSIDERATIONS FOR CITIZEN SCIENCE

In order to design a system that supports citizen science efforts, it is essential to understand the use of technology in contemporary citizen science. First, we review pre-existing projects to understand technology adoption, sensing, and distribution trends. Next, we explore three widely acknowledged user-acceptance factors in citizen science: data quality, privacy and motivation. Lastly, we review authoring technologies through a literature review. We will begin by defining citizen science.

Defining Citizen Science

Citizen science is a form of research collaboration between researchers and volunteers to address real-world problems [9]. Members of the public who volunteer for these collaborations participate in different phases of the research and in a variety of ways [8].

In the simplest case, the citizen science research process consists of three stages: designing a project, collecting data, and analyzing/interpreting collected data [4]. Several studies distinguish participation types and roles of volunteers [38]. Among those, Shirk *et al.* introduced five models on degree of participation: *contractual, contributory, collaborative, co-created, and collegial* [35]. In *contributory* projects, volunteers contribute to collecting data for the project designed by researchers. Projects that aim to produce data on a large geographic or temporal scale often fall under this model, and volunteers participate in the project both in person and remotely via internet [37]. In contrast, *co-created* projects occur when a group of individuals is deeply involved in most or all stages of the research process from designing a project to interpreting data. Community-based projects, like the collaborative monitoring of a neighborhood environment and local data interpretation, often fall under this model [41]. Volunteers participate in the project in person, sometimes utilizing digital collaboration tools such as Internet. *Collaborative* projects are activities for which volunteers are enlisted to help analyze and interpret scientific data. Scientific projects that require a vast quantity of data interpretation fall under this model [10,31], and volunteers can participate digitally.

Mobile devices and web technologies could easily facilitate citizen participation in *contributory, collaborative* and *co-created* projects. The *contractual* and *collegial* models lie at the far boundaries of the spectrum, so we did not explore them in this work.

Use of Technology in Citizen Science

We reviewed over 340 existing *contributory, collaborative* or *co-created* projects registered in an online citizen science repository[1] to understand the use of technology in citizen science.

Technology adoption

Only 39 projects (11%) provided companion mobile applications to facilitate data collection efforts. Compared to a wide adoption range of personal mobile devices, this shows how underrated the use of mobile devices is in citizen science. About 180 campaigns (53%) used websites as their primary point of data submission. These websites relied on custom servers or existing web services such as blogs, SurveyMonkey, Twitter, or Flickr.

Sensing

A common theme among the projects was the use of location meta-data associated with the data being sourced. Location data is both highly relevant to citizen science data collection and easily sensed with smartphone technologies. In the majority of these applications [2,7,23], GPS data was gathered and associated with other information, which varied by the type of observation and equipment used. Photos with accompanying text or numeric data were also common data sources.

[1] http://scistarter.com/

Distribution

The online citizen science repository was the only systemized distribution platform we found. Aside from this, they rely on word-of-mouth approaches such as neighborhood mailing lists and local newspapers for the distribution of their activities.

User Acceptance Factors in Citizen Science

There are several considerations in citizen science. Amongst, we explore three widely acknowledged user-acceptance factors: data quality, privacy and motivation.

Quality of Data

Citizen science relies on volunteers [8]. One potential issue in a system where the crowd becomes the source of data is quality of data [12]. Although data collected by amateurs can be of high quality (*e.g.,* [3,31]), amateur-collected data has potential for accidental submissions of bad data or malicious submissions of data [12]. This is arguably a fundamental issue for citizen science in general. A popular computational approach is redundancy where multiple workers repeat the same task [18]. A reputation model is another mechanism proposed to increase the reliability of citizen-collected data [17]. Meanwhile, Sheppard *et al.* showed that quality could be maintained by implementing a qualitative process, such as training users prior to participation [33] or providing standard data collection procedures to engage volunteers in data analysis [22]. We selected the latter approach for Sensr.

Privacy

Digital citizen science takes advantage of sensor-rich mobile phones and their extensive adoption, turning people from passive consumers to active producers of sensed data. Unavoidably, this raises privacy concerns, as people transfer a considerable amount of personal information when sensing [20]. Sensory data is our digital footprint, embedding details of everyday life. There is an inherent conflict between data sharing and privacy [15]. Location data is a fundamental part of the data being collected in citizen science applications, which when coupled with date and time data raises a number of additional concerns about privacy [39]. There exists an abundance of literature related to privacy concerns and possible solutions in citizen science [7]. Prevalent technological approaches include blurring or fuzzing information from original data [22]. Shilton *et al.* argues that participants should be engaged in the process of decision-making, claiming that urban sensing systems must allow people to negotiate social sharing for them [34]. Anonymizing data and selectively revealing information according to volunteer preference is another approach, which we used in Sensr [7].

Motivation for Participation

Attracting and retaining volunteers is crucial for designing technology-meditated science projects. Thus, motivational factors have to be addressed when building a tool [32]. Researchers have discovered that intrinsic and collective motivations like personal interests, enjoyment, following social norms, or acknowledgement are dominant factors, while reward motives are arguably less salient [26]. While important in citizen science, we did not consider this factor on the authoring side of citizen science in this work.

Authoring Technology for Citizen Science

Lack of technical expertise and resources are often the major obstacles to developing a mobile application. Many groups who wish to develop mobile citizen science applications are non-profits or local groups that lack the resources to hire experts or in-house technical staff to support such development. Beyond programming, managing data poses a significant challenge, as most of these communities do not possess server farms to manage collected data.

Distribution of the application presents another barrier. Current distribution models require financial and logistical coordination for an application to distribute with an application store. This model also results deployment delays and challenges volunteers to find existing applications.

To that end, approaches that support creating a mobile citizen science application have emerged, including participatory sensing, using existing infrastructure, and building a tool to lower technical barriers.

Participatory sensing is a computing paradigm that enables the collection of disseminated data by volunteers. It allows the increasing number of mobile phone users to share knowledge acquired by their sensor-equipped devices in diverse domains. As an example, the CENS group has designed mobile participatory sensing platforms in extensive domains for everyday people to systematically measure and share the world around them [6]. Two sample projects to mention include Campaignr, a software framework for mobile phones in which smartphone owners join data gathering campaigns for personal participatory sensing [19], and PEIR, a participatory sensing application which relies on location data sampled from mobile phones to calculate personalized estimates of environmental impact [23]. While many of the CENS systems have been tremendously successful in designing participatory sensing projects for particular needs, our efforts with Sensr lie in providing an authoring tool to support authoring mobile applications for citizen science.

Researchers have explored ways to use existing systems as an alternative platform to support citizen science. Twitter is one platform that can facilitate the distributed participation of everyday people [13]. While Twitter supports citizen activities in some aspects, it has several limitations: (1) there is little flexibility for customization, (2) it pollutes personal tweet threads, and (3) Twitter is better for announcing time-critical accidents such as disaster reports or rescue activities, less for reporting ordinary observation-type data. To maximize the capacity of mobile devices in citizen science, we claim there is a need to build a citizen science specific platform.

Table 1: Summary of authoring technology design considerations for citizen science

Authoring tool	Use of technology		User acceptance factors		Authoring type
	Sensing	Distribution	Quality assurance	Privacy	
Typical	Various	No support for distribution	Various	Various	Use a custom system or existing system (*e.g.,* Blog, Twitter, *etc.*)
Sensr	Locations/Photos/Text	Automatically launched in a web platform	Filtering/ Validation	Anonymity	Via web Forms
Ushahidi	Various	Automatically launched within an app	Various	Anonymity	xml, PHP and MySQL + custom s/w download or via web forms
Noah	Locations/Photos/Text	No support for distribution	Collection process	Social Negotiation	No support for authoring
Epicollect	Locations/Photos/Text	No support for distribution	Not specified	Not specified	Via web Forms

Recently, a small number of web platforms and tools that focus on simplifying the authoring process have emerged [1,19,21,28,30]. For example, Ushahidi is a web-based collaborative reporting environment that aggregates and shares information provided by citizens [21], and Open Data Kit (ODK) helps organizations author, field, and manage mobile data collection solutions [27]. While powerful and very flexible, most platforms require programming skills and/or infrastructure in some degree. Basic knowledge of xml, PHP, and MySQL is required to use ODK and Ushahidi. Authors need JSON for Pachubu, XML for Campaignr, and custom software download for Ushahidi. Most also require infrastructure.

Two platforms support authoring without programming: Project Noah and EpiCollect. Project Noah is a tool for citizens to explore and document wildlife [30], and EpiCollect allows people to collect and submit data to a central project from mobile phones [1]. Neither supports the variety or complexity that Sensr supports. Project Noah focuses on wildlife exploration, and EpiCollect supports application creation but not a distribution platform where volunteers find or subscribe to campaigns. Table 1 summarizes some of the design options applied to existing systems we observed.

Other Usability Factors

Studies of the data collection needs for mobile fieldworkers [29] reveal several usability factors to consider. First, when possible, a user's attention must be focused on the observation of the event or object, not on the interface. Also, a user should be able to enter data quickly and accurately across a variety of usage contexts, such as sitting, standing, or walking, and the interface needs high contrast colors for outdoor use. Finally, it should support a range of data fields to satisfy varying user needs.

Summary of Design Considerations

As summarized in Table 1, we applied the following design considerations, drawn from our literature reviews and field studies in designing Sensr to ensure usability in both *mobile* and *citizen science* applications.

Sensing: Photo and location data with a map and accompanying text inputs are essential in fieldwork type activities.

Distribution: A platform to share and review reported data among volunteers is needed but rarely provided.

Quality assurance: Simplifying the measuring and observing process is crucial to lowering the entry bar for amateurs' participation and to data quality

Privacy: Anonymizing data and selectively revealing information by volunteer preference reduces privacy threat.

Authoring type: Using web forms will make it easy to author a campaign.

SENSR: SYSTEM & IMPLEMENTATION

To take full advantage of mobile technologies, it must become easy to develop digital citizen science campaigns on mobile devices. Sensr aims to do precisely this, providing a transparent campaign-creation interface for people with limited technical skills to easily create campaigns to which users of the Sensr app can subscribe and contribute data. To clarify our work, we provide

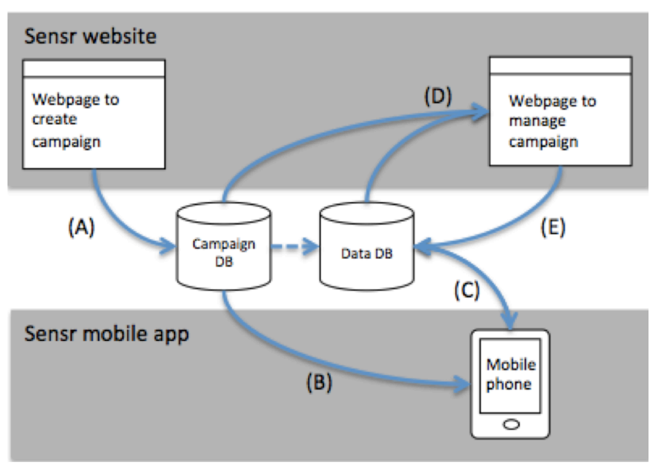

Figure 2. Functional architecture of Sensr; (a) campaign schema is saved to a server; (b) campaign schema retrieved to a mobile app; (c) reported data transfer between a server and a mobile app; (d) data retrieved to a web page; (e) discussion data saved to a server

several definitions: a mobile citizen science request for data collection is called *a campaign*, a person or organization who creates and manages the campaign is refereed to as *an author*, and an individual who contributes data to a campaign is *a volunteer*. As shown in Figure 2, Sensr system consists of two parts: (1) a website hosted through Amazon Web Services where authors create and manage campaigns, and where the public can access the list of active campaigns along with data visualizations, and (2) a mobile application with which volunteers can explore, subscribe to, and participate in campaigns.

For the server, we created two separate MySQL database tables: Campaign DB and Data DB. Campaign DB stores the basic schema of a campaign, including an interface structure, GUI components, and the general campaign information. Data DB stores data that volunteers report via the mobile application as well as discussion entries submitted from website. Then JSON serializes and transmits data over the network (see Figure 2). We used jQuery UI, Ajax, and PHP to build the interactive webpage where people can author a campaign. To build a mobile application running on iOS, we used objective-C with Apple's Cocoa API. We are planning to build a mobile app for Android in the near future.

Website experience

When designing the website, our main concern focused on accessibility for people without programming skills when authoring and managing campaigns. For that, we provide only two steps to create a campaign: (1) completing a general information page to describe the campaign, and (2) designing a data collection user interface using a simple drag and drop method.

Figure 3. Screenshots of mobile application creation from the website. Information entered in the html fields on the left automatically appears on a replica iPhone screen (top). An author can drag and drop widgets from a predefined set onto replica iPhone screen to design one's own application (bottom).

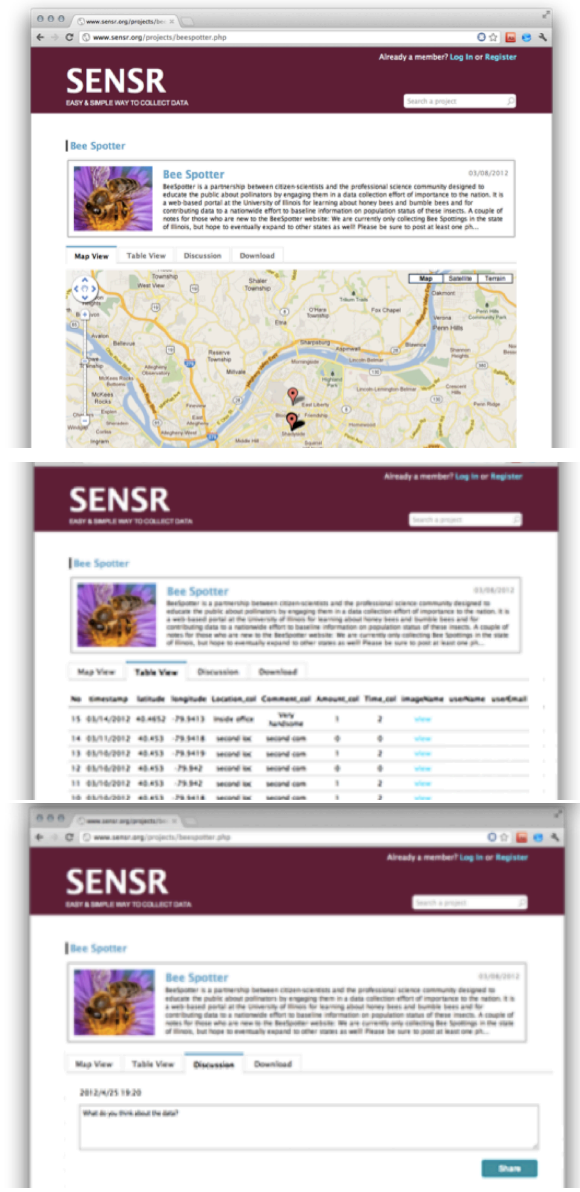

Figure 4. a website where all information and aggregated data for the campaign display. Collected data is displayed in two different formats: map and table (top and middle). People can discuss and share opinions about the campaign and relevant issues (bottom).

First, the author provides general information about the campaign, including a title, contact information, campaign description, a logo image, *etc*. The author's input is automatically displayed on a mock-up iPhone interface adjacent to the form. This page will be displayed on the mobile application when volunteers explore existing campaigns (See Figure 3 top).

Second, the author designs the data collection user interface by dragging and dropping widgets from a predefined pallet onto a simulated iPhone screen (See Figure 3 bottom). Following the guidelines for designing a mobile application we set in the previous section, widgets are selected from iOS user interface elements. Three different types of widgets are provided: photo, radio buttons (with two or three options), and a freeform text entry field. Currently, only one photo widget is allowed per report (a feature to submit multiple photos is to be added in the next version); however, multiple radio buttons and text entry fields can be added. Radio buttons are especially useful because they prevent users from struggling to type on the go.

On the mock-up iPhone screen, the author can rearrange the order of widgets, delete a widget, and edit the labels of widgets. Besides the widgets volunteers need to complete, the system automatically captures other sensor data such as a timestamp and GPS location. This page will be used as the mobile interface for volunteers to report data.

When satisfied with the design, the author submits the final campaign interface, which is then automatically converted into a version accessible by mobile application. a key feature of our system is that it avoids the technical burden, complexity, and cost of submitting apps to an app store for approval and distribution. Sensr uses an *in-app* subscription system to allow easy browsing, subscription, and removal of campaigns within the mobile application.

Once the campaign is created, the system automatically generates a hosting webpage to display all information and collected data for the campaign (See Figure 4). From this page, the author can modify campaign information, and view, filter, and operate aggregated data. This data is displayed in three different formats including a map-based visualization, a table view, and a downloadable file format. Additionally, the system provides a webpage where people can discuss and share opinions about the campaign. While the current discussion boards are primitive and lack novel features, we plan to expand its functionality to support collaborative discussion and analysis of the data in the final version [22,16]. The campaign's hosting page and data visualizations can be open to the public or shared among volunteers upon the author's setting.

Mobile application experience

On the mobile application, volunteers can subscribe to campaigns and collect, report and review data. The interface consists of three tabs: My Campaigns, My Data, and Settings (See Figure 5). The first tab, My Campaigns, lists all campaigns to which a volunteer is subscribed. When a volunteer wants to participate in other campaigns, he can visit the [add campaigns] page to explore campaigns by category or to search a particular one using a unique ID provided when a campaign is created. A volunteer clicks the [*participate*] button to subscribe. Then, the campaign is listed under My Campaigns. Clicking the title of each campaign leads to its main page where volunteers can explore existing data on a map or list view. A volunteer clicks the [*report*] button on this page to report data. The report page interface differs by campaign, according to the author's design. When connected to a network, volunteers can report data on the fly. Sensr also supports a critical citizen science feature of offline data collection by saving data locally and uploading it later when networked.

The second tab, My Data, stores data reported by the volunteer. Under the Settings tab, a volunteer can optionally set personal information including name, email, and place of residency. If a volunteer sets personal information to expose, it will be included with other report data when reported. Otherwise, personal information will not be included. Even when submitted, personal information is only visible to the author of the campaign.

Figure 5. Mobile application screenshots. From left to right, a list of campaigns a user added, a category to find and add a campaign, a campaign main page that can be viewed by map or list view, a repository of the data, and a customized form to report data

CASE STUDY

In this section, we describe a case study in which we presented Sensr to seven participants, who were interested in initiating mobile citizen science campaigns across three different organizations. Our objectives were to uncover how quickly and easily authors without technical skills could develop and maintain campaigns using Sensr, and to expose any system flaws before the application's launch. The method was as follows. First, managers from each organization gathered to discuss campaign organization issues in terms of volunteer recruitment and data collection. Next, we presented a working prototype of Sensr and explained its purpose. Managers browsed the interface before selecting one of their activities to deploy in Sensr. They created a mobile application using the Sensr website and tested the resulting mobile app in a separate room. Finally, the managers regrouped to discuss issues, benefits, and difficulties in using Sensr. All sessions were recorded and relevant portions have been transcribed.

Case Study 1: Air quality monitoring

Group Against Smog and Pollution (GASP, http://gasp-pgh.org) is a non-profit organization in Southwestern Pennsylvania working for a healthy, sustainable environment. Founded in 1969, GASP has been a diligent watchdog, educator, litigator, and policy-maker on environmental issues with a focus on air quality. GASP selected a diesel cleanup initiative to create a campaign.

Diesel Clean-Up Campaign

Diesel exhaust is one of the nation's most pervasive sources of toxic air pollution. Diesel engines, such as buses, trucks, trains, and construction equipment, are known for their durability, but older engines emit a toxic mixture of particles, metals, and gases including over 40 hazardous air pollutants as classified by EPA [14] unless properly maintained. While old diesel engines are known as a major source of diesel exhaust, it is relatively difficult to collect evidence because incidents are transient, and the exhaust disappears within several seconds. Distributed urban sensor nodes (*e.g.,* citizens equipped with smart phones) can be an appropriate medium to capture such incidents. GASP has sought ways to encourage everyday people to monitor neighborhood diesel emissions and share experiences with visual evidence like photos or videos. A photo of a fuming vehicle's license plate could be great evidence against companies with illegal emissions control. While aware that the use of a mobile application will facilitate their efforts, lack of software development skills has hindered GASP from developing a mobile application.

Creating a campaign

Three managers used Sensr to create a campaign, and they did not have any problems interacting with the web interface. Everyone easily figured out how to interact with the drag-and-drop interface and created a campaign with few mistakes. We did not find evidence for any usability issues when interacting with our system. The final interfaces were identical across managers: one photo and one comment field widget. We assume this is because the campaign is already underway, making the design of an interface for a mobile application obvious.

Issues and possible solutions

Data quality was of particular concern to this organization for several reasons. First, the party who contributes data is the error-prone general public. Also, a participant's data report could include photos containing inappropriate content, which would be detrimental to their reputation. However, the authors who tried Sensr felt that Sensr's mechanism for handling this issue addressed their concerns. Sensr provides a filtering process with which an author can confirm data before displaying it in public to ensure its quality. While this mechanism brought up a separate concern about extra time spent filtering data, they agreed to manage such commitment if it increased citizens' participation and the amount of useful data collected.

> *"There are always people who try strange things. We are the ones who officially organizes and runs this data collection activity. I am worried if people may think that our activities are full of useless incidents if the data quality is not decent."*

> *"Our logo will be put on top of all these data. We do not want to represent any junk data, and need ways to control its quality."*

While mostly satisfied with Sensr, they found it lacks the support for localization. Many grassroots activities are based in a particular area where locals monitor neighborhood environments. Because GASP runs activities solely for and within the Southern Pennsylvania region, they have no means to act upon data from outside the supported area. To prevent such wasted efforts, they suggested a feature to author a campaign by region.

> *"It won't hurt if someone in California reports us a picture of diesel emission there. But we can do nothing about it. Then that person's effort becomes useless... It would be nice if we can specify a locational boundary."*

Case Study 2. Watershed monitoring

The Mountain Watershed Association (MTWatershed, http://www.mtwatershed.org) focuses on the conservation, restoration, and protection of watersheds in Pennsylvania. They aim to remediate abandoned mine discharges, develop community awareness, promote cooperative community efforts for remediation, and encourage sound environmental practices. MTWatershed selected a Marcellus visual assessment program for a campaign.

Marcellus Visual Assessment Program

Marcellus shale is a rock formation that underlies approximately two-thirds of Pennsylvania and the adjacent area. The shale is believed to hold trillions of cubic feet of natural gas. Recently developed drilling technology makes extracting natural gas from the formation more feasible. The drilling process relies on a mixture of chemicals and a large amount of water, ranging from 3 to 7 million gallons, which may be illegally dumped afterwards, causing serious water and environmental pollution. MTWatershed offers a basic training course, called the Marcellus Visual Assessment program that instructs how to monitor Marcellus drilling sites. People learn to use their sight, hearing, and smell to identify potential issues resulting from drilling operations on site. Then they go into the field, observe sites, and come back home to report data via an online form in the website. Since location information is critical, MTWatershed wants to develop a mobile application to automatically capture geo codes. However, their limited resources and technical skills have hindered them from developing a mobile application.

Creating a campaign

Two managers created a campaign on our system and did not have any problems interacting with the web interface. Everyone easily figured out how to interact with the drag-and-drop interface, creating a campaign with few mistakes. While we did not find evidence for usability issues, we saw a disparity in the final two interfaces: one interface was almost identical to the online form currently used by the organization, and another interface modified the current form with an additional photo widget and fewer data fields. (The preexisting form consisted of seven selection fields and eight text-entry fields to report.) They explained that one manager simply copied the existing form to a mobile campaign while the other tried to adapt the existing format for the mobile interface. Even though an existing campaign was converted, the result conflicts with the finding from the previous case where the final interfaces were identical across managers. This finding reveals that the complexity of the preexisting form influences the mobile application design. The form in the previous case had only two data fields, which made it easy to translate to the mobile version, while the form in this case had fifteen data fields.

Issues and possible solutions

The discrepancy between the interfaces reflects a possible difficulty when creating a mobile version of existing campaigns. The current data entry form was not applicable to a mobile interface because it was lengthy and complex. In such cases, modifying an existing form is necessary to sustain mobile usability, which in turn causes the disparity in the formats of data collected from different media. Since the activity was already underway, the managers were hesitant to generate a separate module for a mobile version. This suggests the need to build in prompts to guide authors toward mobile-friendly interfaces. Through discussion, they optimized the form suitable for a mobile platform.

"I know that it cannot be the same from a web form to a mobile one. But I don't want to have two different sets for the same activity. We can merge a few questions to reduce the number of fields, and add a photo to remove some."

"Our current format is somewhat complicated as it needs to measure data using sensors we lend. If we can make it simple to fit into this system, we will have more people participate in it."

They raised another concern about the possibility of malicious data use. Public access to the data has both benefits and disadvantages: the aggregated data show volunteers where popular monitoring sites are and where more data is needed, but it also tells companies which locations are rarely monitored and thus, would be ideal for illegal dumping sites. The managers did not come up with any specific solution, but all agreed that more citizen participation would cover more sites and lessen the chance for such ill-purposed use cases.

"We monitor illegal wastewater dumping. If companies know where people are monitoring, they could use that information to find a site where no one monitors so that they can go dumping wastewater there."

Case Study 3. Local Parks Conservation

The Pittsburgh Parks Conservancy (http://www.pittsburghparks.org) was founded two decades ago by a group of citizens concerned with the deteriorating conditions of Pittsburgh's parks. The Conservancy participates in all aspects of park management to improve parks and thus, boost quality of life for the people of Pittsburgh. They conduct projects with environmental sensitivity, respect for the parks' historic landscape design, and an appreciation for the recreational needs of modern users. The Conservancy selected to create a campaign for an invasive species management program.

Invasive Species Management Program

Although many plant species are introduced to the United States from other countries without causing ecological damage, the small percentage of non-native plants that become invasive can have a devastating impact. Left unchecked, invasive species can completely take over sections of parkland, killing a wide variety of native vegetation and destroying the biological diversity that creates habitat for wildlife and keeps an ecosystem functioning. The Conservancy has been working to monitor and control the spread of invasive species in the parks. Volunteers can help by simply comparing plants in the wild with a provided list of invasive plants and reporting suspicious plants to the Conservancy. Currently, this program is only devoted to educating community members about invasive species and the proper way to remove them. Since school children partake in a variety of extracurricular activities at parks, the Conservancy has sought ways to encourage these children to participate in the program using mobile phones. However, lack of technical skills has been an obstacle.

Creating a campaign

Two managers used Sensr to create a campaign. While we did not find evidence for usability issues in interacting with our system, both managers struggled to create a campaign from the provided widgets alone. They wanted to create an extra page to display pictures of invasive species that the system does not provide. Setting this aside, both managers came up with similar interfaces consisting of one photo widget and a couple text and selection fields for extra information about the photo. After a discussion between the managers and researchers, they decided to create a web page to display pictures of invasive species, and link it to the campaign's mobile page to fulfill their needs.

Issues and possible solutions'

We did not find any usability issues from the case study with this organization, but they demonstrated a strong intent to use Sensr as a tool to reach broader populations.

The Conservancy has sought ways to promote youth participation in their conservation activities. The manager said that it was particularly difficult to make students interested in the activity. The managers appreciated the ease with which Sensr allowed them to operate a mobile application since the use of mobile devices would more easily allow and excite younger participants.

> *"It is hard to reach out younger population. Having a simple mobile application like this, we can attract high school kids!"*

IMPLICATIONS

The case study with three organizations highlighted several design implications for the authoring interfaces of mobile data collection tools for citizen science.

A guide to manage data collection from various platforms is needed

Sensor-equipped mobile devices are an apt platform for citizen science data collection but not the only platform an organization may use. Many campaigns are already designed for and executed on other platforms, such as paper or a website. This raises the issue of modifying pre-existing forms designed for other platforms to suit mobile devices. A mobile interface should be simpler than a paper or web form because of its screen size. However, pre-existing campaigns are often long and complex. This suggests the need for deeper considerations to help authors make a rational decision in transfering existing forms designed for various platforms to the mobile interface. Tools that could support the integration of data across platforms would be of value. Furthermore, as data collection platforms become varied, guidelines to manage data collection efforts for a campaign through various platforms need to be explored.

Location information is crucial for privacy and beyond

We learned from a literature review that location is crucial to interpreting data and protecting privacy and will work will need to continue in addressing this issue [7]. Our case studies also confirmed the essential nature of location data. Our participants were interested in a broader use of location than has been reported in the past. For example, participants wanted to know more about gaps in where data had been gathered to improve volunteer participation in a targeted way. Automated identification of "data quality gaps" could be a valuable area for future work.

Expert review ensures data quality and a feeling of control

Past work has pointed to data quality as an area requiring careful attention in citizen science campaigns (*e.g.,* [3,31]). Our study shows that many experts still doubt the quality of amateur-collected data. Sensr provides a filtering option that allows a campaign author to confirm collected data before displaying it publicly. This review step relieved authors' concern about amateur participation in scientific work. Future work could include tools that learn from author confirmation and eventually predict problems and highlight them automatically to campaign authors.

Mobile applications further increase public engagement and education in citizen science

Citizen science plays an important role in improving the public's scientific literacy [4]. While the direct effects of public participation may not be visible, volunteers learn to identify relevant phenomena and generate local knowledge, which can result in an active citizen advocacy [38]. All authors from the case study emphasized their belief that mobile applications would further promote public engagement, increase awareness of their activities, and provide volunteers with informal science education. In particular, mobile devices can be an effective medium to increase youth interest in participation. While usability and usefulness were our main considerations when designing Sensr, perhaps entertainment and enjoyment should also be considered to further increase engagement and educational aspects of citizen science.

CONCLUSION

The proliferation of mobile devices in our everyday lives has provided a rich sensor environment for citizens to observe, measure, and evaluate their world. However, technical barriers have prevented people from taking full advantage of the opportunities of these sensor rich mobile data collection platforms coupled with crowd sourcing..

This work has two major contributions to the fields of HCI and social computing for the proliferation of citizen science. Our primary contribution is Sensr, an authoring tool that overcomes the technical barriers in developing mobile applications for citizen science. We validated Sensr in a case study with seven participants at three local organizations. Our findings point towards a promising potential for digital citizen science on mobile technologies to expand participatory data collection efforts. In the future, we will deploy Sensr for further studies focusing on the volunteer use.

Through a case study, we validated that Sensr successfully helped people without technical skills author mobile citizen science applications. Furthermore, it revealed real-world issues in authoring mobile citizen science applications such as difficulties translating existing campaigns to mobile-friendly reporting interfaces and the unexpected uses of collected data.

While this paper focuses on the authoring side of Sensr, a secondary contribution is a broader exploration of design considerations for technologically enhanced citizen science projects for both authoring and volunteering.

Technologically enhaced citizen science has the potential to expand participatory data collection efforts, increasing the public engagement in problems that directly relate to everyday lives, health, and environmental issues. We hope to further this work and inspire others to contribute towards the emerging field of citizen science.

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