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Public Participation, Trust and Data Sharing: Gardens as Hubs for Citizen Science and Environmental Health Literacy Efforts

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Abstract

Gardenroots: A Citizen Science Project (2015) is the product of a needs assessment, revealing environmental quality concerns of gardeners living near hazardous waste or resource extraction activities. Participants were trained, collected garden samples for analysis, and later received their data visualized (individual and aggregated) via community events or mail. This article describes participant motivations, changes in knowledge and efficacy, and whether these depend on the mode of data sharing and visualization. Motivations were internal, and self-efficacy increased, while knowledge and satisfaction were higher in event attendees due to increased researcher contact. This reveals importance of data-sharing events, data visualizations, and participatory research processes.

Keywords

Environmental Communication; Data Visualization; Citizen Science

Introduction

Twenty-five percent of Americans live near a hazardous waste site (U.S. Government Accountability Office, 2013). Every year there is, on average, 1,100 sites on the United States Environmental Protection Agency's (U.S. EPA) National Priorities List under the Superfund program slated for cleanup (Gomez, 2015). In Arizona alone, there are eighteen Superfund sites (U.S. EPA, 2017). Exposure to pollutants via soil is particularly important to examine, especially when families are gardening and growing foods (Ramirez-Andreotta et al., 2013a). In 2013, 42 million households gardened at home and three million grew food at a community garden. Community gardens have been shown to help address social and economic constraints on health by increasing access to wholesome foods, improving community building efforts, creating green space, and reducing the cost of foods (Teig et al., 2009). However, it can also serve as a route of exposure to contamination (Brand, Otte, &

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Lijzen, 2007). The risk of adverse health effects depends on the level of contamination in the soil and water, the contaminant uptake and translocation within the fruit or vegetable, and consumption rates. A gardener who neighbors a Superfund or hazardous waste site needs to be particularly aware of their soil quality and the potential for uptake of contaminants through their vegetables.

Throughout the cleanup process at hazardous waste sites, there is little bi-directional communication between site managers and the residents and public participation in the exposure assessment and risk decision-making process. A Decide-Announce-Defend (DAD) approach is traditionally used by a state or governmental agency who decides the acceptable risk and clean-up goals, announces it to those affected, and then holds a question and answer session (Depoe, Delicath, & Elsenbeer, 2004). This method has proven successful in emergencies, as these events require quick, immediate action, but in other situations like living near spaces with a potential chronic, low level contaminant exposure, citizens feel left out of the decision-making process and that their concerns were not addressed (Depoe et al., 2004). Often, lifestyle changes and suggestions made by managers may not be applicable to the public, who may want a more personalized risk communication approach (Chess & Purchell, 1999). Past studies have demonstrated communities intrinsic interest and ability to make informed decisions if given access to exposure assessment data and given the opportunity to participated and engage in the risk assessment and communication process (Ramirez-Andreotta et al., 2016b, Ramirez-Andreotta et al., 2015).

Using gardens as hubs for environmental health research and education due to their frequency of use and the potential for exposure to contamination, the goals of *Gardenroots: A Citizen Science Project* (referred to as Gardenroots) are to: 1) engage community members in the environmental monitoring and exposure science process, 2) evaluate environmental quality (water, soil, and homegrown vegetables) and potential exposure routes, 3) design personalized results booklets via information design, and 4) share the results with participants to inform their for environmental action and decision-making. Gardenroots employed a public participation in scientific research (PPSR) approach as defined by Shirk et al., 2012. PPSR is a type of informal science education and involves partnerships between the public and researchers to generate new knowledge (Shirk et al., 2012). Gardenroots, is a collaborative PPSR study, meaning that the public is involved in many steps of the research process itself, including disseminating results and translating results into action (Shirk et al., 2012). Participants can increase their knowledge and curiosity on the subject (Ramírez-Andreotta et al., 2015, Stepenuck & Green, 2015) and gain a sense of contribution and community (Jordan, Gray, Howe, Brooks, & Ehrenfeld, 2011). These outcomes may lead to changes in behavior and increases in self-efficacy (Sandhaus, Ramírez-Andreotta, Kilungo, Wolf, Sandoval, & Henriquez, 2018; Jordan et al., 2011).

Theoretical framework

To set the stage for the research described here, we used the following theoretical frameworks: self-efficacy and motivation, the community-first communication model, and the Visualization Wheel framework. Self-efficacy is defined as the confidence and ability to have control over one’s own life (Janz, Champoin, & Strecher, 2007) or ‘an individual’s belief (or confidence) about his or her abilities to mobilize motivation, cognitive resources, and course of action needed to successfully execute a specific task within a given context' (Bandura, 1997). An individual who feels that they have no control over their lives and that their life is subject to chance or external forces is said to have low self-efficacy or *amotivation* (Vallerand, 2001; Hardcastle et al., 2015). Establishing efficacy is an important step in determining whether a targeted population will increase their environmental health literacy and value the public health intervention. While a sense of control and confidence is important, one must also consider the factors that motivate or amotivate (Vallerand, 2001) individuals to engage in acts of environmental public health prevention and interventions. When working with communities neighboring hazardous waste sites or those living in environmentally compromising spaces, individuals are intrinsically motivated to understand their environment and how it may affect their health and believe that the benefit of intervention outweighs the cost, are willing to invest in learning and intervention efforts, hence, increasing their environmental health knowledge and efficacy (Ramirez-Andreotta et al., 2016b).

Reporting exposure data back to study participants is increasingly critical and can increase self-efficacy, particularly when working with underserved communities (Ramirez-Andreotta et al., 2016c). Data sharing can be a form of public health intervention and can increase the likelihood of translating the results into action (e.g. Brody et al., 2014, Ramirez-Andreotta et al., 2016a). In this study, a community-first communication model is used as proposed by Emmett et al. (2009). This means, while maintaining credibility and once the investigator(s) is comfortable, the results should be released promptly, individual participants should receive their results first, and communication efforts must be contextualized and minimize pointless concern (Emmett et al., 2009). This method of data sharing can lead to increases in trust between researchers and communities and trigger behavioral changes at the community level (Emmett et al., 2009). Other researchers have documented that participants who have been part of report-back efforts experienced an increase in environmental health literacy (e.g. integrating concepts, mitigating exposures, reducing health risks), trust in science, and capacity building at the individual and community level (e.g. Brody et al., 2014, Ramirez-Andreotta et al., 2016a).

Integral components of report-back efforts include information design. For data sharing to serve as an effective public health intervention, the information needs to be presented in plain language and the data needs to be effectively visualized. Visual representation of data is a crucial component of contemporary science communication and is referred to as functional art (Cairo, 2013). Cairo combines graphics and design with cognitive psychology, information processing, and mental models. When considering the functionality of information design, Cairo presents the Visualization Wheel "as a framework from which the utility of data-driven graphics can be characterized and assessed" (Spencer and Ruel, 2012). Information design is critical to the user's ability to process complex data and link individual results to their local environmental quality, which is essential in exposure science report-back efforts. Design and provided visualizations can affect an individual's interpretation, uptake of information, and how they see their choices affecting their environment and future (Nicholson-Cole, 2005). Since imagery can elicit different responses from people depending on background, previous knowledge, motivations, and personal beliefs, it is critical to engage and learn about one's targeted audience. Science communication efforts need to investigate how to create an accurate and appropriate visual representation of the information and how the intended audience will perceive the data (Nicholson-Cole, 2005).

The objectives of this study are to evaluate: 1) participant motivation in the Gardenroots project, 2) the utility of data-driven graphics used in the Gardenroots results booklets and 3) individual knowledge and efficacy as a result of the environmental data risk communication efforts. We hypothesized that a collaborative citizen science project combined with community-first reporting and effective data visualizations would increase participant's self-efficacy and capacity to make personalized decisions about their risk and trigger individual prevention and intervention strategies.

Materials and Methods

Initial needs assessment

The Gardenroots model was established in 2010 in collaboration with a rural community neighboring a Superfund site (Ramirez-Andreotta et al., 2013a, 2013b, 2015). Based on the successes of this work, the Principal Investigator (PI), wanted to determine whether Gardenroots was of interest to other Arizona communities. A 'Garden and Environmental Health Needs Assessment Survey' was administered on March 12, 2015 at the 22nd Annual High Desert Gardening and Landscaping Conference sponsored by the Arizona Master Gardeners and Cooperative Extension (N~110). The needs assessment asked individuals a variety of open-ended questions, such as 'Do you have any questions about your garden that you would like to have studied?" and "As a gardener, do you have any environmental or health concerns?'. Thirty-four conference attendees completed the survey. Community members expressed concerns regarding their soil, water, and plant quality (see Figure 1). Based on the results of this needs assessment, Gardenroots was launched in summer 2015 to help address community concerns regarding their soil, water, and plant quality.

Site description and study population:

Gardenroots participants lived in the following counties in Arizona: Cochise (population = 126,427), Apache (population = 71,474), and Greenlee (population = 9,529) (US Census Bureau, 2015). These counties are mostly rural and when compared to the state of Arizona and United States as a whole, have a higher percentage of individuals who are: minority, low-income, above 65 and have a high school or less education level (U.S. EPA EJ Screen Tool, 2015). Table 1 details the number of participants who completed each evaluation activity (discussed in the next subsection).

Training, sample collection, and report back:

Based on these results and the interest of cooperative extension personnel, promotion and recruitment activities took place between March-June 2015. By June of 2015, over 90 community members were trained in sample collection protocols. By December 2015, Two-hundred and sixty-seven plant, 174 water, and 125 soil samples were collected and 63 kits were returned for analysis. The participants worked with researchers to determine what inorganic elements they suspected were in their soil based upon current and past land uses near or neighboring their gardens.

To maintain contact and manage expectations, emails and postcards were sent to all participants detailing the Gardenroots methodology and current status of the project. As a participant's sample moved through the sample preparation and laboratory analysis process, the participant received email updates and postcards highlighting the step in the process (Figure 2).

Once all the samples had been analyzed and the data visualizations prepared, five standardized data sharing events (Figure 3) were held. The events were held in each of the three counties: Morenci (Greenlee county), St. Johns (Apache county), and Bisbee, Sierra Vista, and Willcox (Cochise county). To standardize the data sharing events, every meeting had the same agenda, presentation, and order of events. Each participant was given a personalized results booklet, containing a brief overview of the project along with a list of important terms before moving on to individualized water and soil results (Table 2). Results for plants were grouped by individual vegetables and were followed by exposure estimates of how much of their homegrown vegetables residents could consume at different increased excess lifetime cancer risk levels. The booklet ended with information about selected contaminants of concern and references for further information. The participants were given time to read through the packet on their own, and then a presentation was given discussing the county's results and how to interpret the data visualizations and provided tables.

Information design

Gardenroots used a variety of data visualization data sharing methods to illustrate the participants' levels of contaminants in their water, soil, and plant samples. Each personalized results booklet was 7.5" × 7.5" and 35 pages long. Traditional methods, such as tables, were used to convey plant data in the booklet (Figure 4). In these tables, a user could compare the plants grown in their county to the U.S. Food and Drug Administration's (USFDA) Market Basket, 2014 Study (fresh weight, milligram per kilogram-mg/kg) and the World Health Organization's Codex Alimentarius non-enforceable, but recommended maximum concentrations in mg/kg, which exist for cadmium and lead only. Experimental visual formats were used for the water and soil sections of the individualized booklets so participants could see their contaminant level compared to reference values and corresponding samples collected in their county (Figure 5).

Surveys, group interviews, and one-on-one interviews:

This project was reviewed and approved by the University of Arizona Institutional Review Board. Pre- and post-surveys were designed to evaluate motivations and possible changes in efficacy of the participants (Supplemental Material1). The pre-survey was given prior to the training, while the post-survey was given after participants received their data and sat through the data sharing presentation. The surveys consisted of open and closed ended questions and statements (Supplemental Material 1). To measure motivation for: science learning, science engagement and environmental action and self-efficacy for learning science, doing science, and environmental action, statements were given and participants were asked to what degree they agree or disagree (Likert Scale; where 1 = strongly disagree, and 5= strongly agree) with each statement (Cornell Lab of Ornithology, Developing, Validating, and Implementing Situated Evaluation Instruments Scales, 2015). There were 49 pre-surveys completed and 16 post-surveys completed.

Group interviews were held with attendees of the data sharing events after the post-surveys were completed, ranging from 2–5 people. Questions were asked to elicit outcomes and changes in efficacy and reasons for participating in Gardenroots as well as to evaluate the overall Gardenroots program, their experience as a whole, and the functionality of the results booklets. Each participant was encouraged to respond, and it was emphasized that there were no wrong answers.

Three months later (March/early April 2016), fourteen one-on-one semi-structured interviews were completed by phone. Twenty percent of participants from each county were included in these interviews. Half of the interviews were conducted with people who had attended the data sharing events and participated in the group interviews, and the other half were conducted with participants who did not attend. The interviews delved into participant's knowledge and expectations of the project.

Analysis:

All surveys were de-identified, numbered, and logged in Microsoft Excel (Microsoft Corporation, Redmond Washington 2013). To analyze the data, IBM SPSS (Statistical Package for the Social Sciences-SPSS) Statistics 24 (IBM Corporation, Armonk New York 2016) was used. Average and standard deviations were calculated for each Likert-Scale question in SPSS. Significance testing was done using the Wilcoxon Signed-Rank test ($p = .05$). A dependent t-test could not be used, as the data was not normally distributed using the Shapiro-Wilk Test of Normality. Significant changes are denoted with an asterisk, and graph error bars are one standard deviation. As there were fewer post-surveys completed than pre-surveys, the only surveys that were analyzed in this study were those from individuals who had completed both the pre- and post-surveys.

To analyze the group interviews and one-on-one interviews, all sessions were recorded and transcribed using VerbalInk (VerbalInk, Los Angeles CA 2017). The group interviews and one-on-one interview transcriptions were imported into NVivo (QSR International, Melbourne Australia 2016), a program for qualitative data entry, coding, and classification.

Results

Below, the results and discussion are summarized by the following sections: motivation, efficacy, knowledge, and functionality of data visualizations. The quantitative and qualitative datasets are combined by measured outcome. When possible, datasets are linked to provide an in-depth analysis of the Gardenroots project outcomes.

Motivations:

Within the survey, the following three statements had significant ($p < 0.05$, denoted with an asterisk) changes from the pre- to the post-survey: 'I chose to learn and understand environmental quality because they are required to understand environmental quality topics' (M3), 'I engage in environmental monitoring activities because they are fun to do' (M9), 'I protect the environment because I am concerned about what could happen to environmental quality if they don't do anything' (M29). Supplemental Material 2 shows the means for the motivation category in the pre- and post-surveys. As outlined by the Cornell Lab of Ornithology DEVISE project(Cornell Lab of Ornithology, 2015), the average external motivation scores were subtracted from the average internal motivation scores for both the pre- and post-surveys. Based on this calculation, participants were internally motivated (values were positive) and this can indicate sustained motivation and commitment to a particular action over time. This is supported by the group interview data. When participant's discussed reasons for participating in Gardenroots, they primarily fell under concern for health (n = 9), followed by education/learning (n=4) and evaluating the health of and growing food (n = 4). One participant stated 'I've been connected to health my whole life, so it was very much a health thing'. Another was interested in the information they would receive, saying 'for me it was a desire to learn. I enjoy information'. When asked about whether they could see how they were contributing to the study, all who responded (n = 10) agreed that they did through their participation, with one participant saying: 'With accumulating information we can see the impact in our area'.

During the one on one interviews, participants anticipated getting information on their soil, water, and plant conditions from participation in this project, as well as best gardening practices (Table 4). Those who attended the data sharing events stated that results were what they primarily received from participating in Gardenroots. Those who did not attend listed both results and general information as what they gained. One participant who attended the data sharing event said: 'I got the information I needed to know where I should and shouldn't be gardening', while another who did not attend said that they got to see pollution levels in the area. Further, those who attended the data sharing events felt like their expectations were met, more so than those who did not. When asked what motivates them to be involved in environmental action, those who attended the report backs gave responses that fell under the coded theme 'environmental preservation' as their primary reasons for participation, including things such as keeping the environment as it is and preventing further degradation, while those who did not attend stated environmental preservation and care for food and its importance. Two participants who did not attend the data sharing events stated their experience living in a rural or agricultural setting as a reason, as they felt that they were closer to nature and had more experience with it than their urban counterparts.

Efficacy:

There were no significant changes in any individual efficacy question observed between the pre- to the post-surveys in any of the self-efficacy categories, however, when pre- and post-means of the whole categories were compared, the self-efficacy for doing science category had a statistically significant increase ($p = .037$) from the pre- to post-survey. The means for the self-efficacy categories in both the pre- and post-surveys can be found in Figure 6. During group interviews, when participants were asked if they were more, less, or equally likely to be involved in environmental action as a result of participation in Gardenroots, all who responded said that they were more likely to be involved (n = 9). Those who responded as such said that they would use the results from this study to educate others in their communities. Some participants commented that they saw 'the power of people working together' and some felt that since they had concrete information to show, they were better equipped to go out in their community and educate others. All respondents said that they felt capable of creating change in their communities. When asked if they would do another citizen science project, ten out of eleven respondents said that they would, and one participant said that they were already signed up for another. Table 3 shows the responses for the group interviews. Not every participant responded to every question, and in some cases, some participants had multiple answers, and for this reason, responses may not add up to the full 12 participants, or may exceed this number.

Interview and group interview data directly support one another (Tables 3 and 4). Regardless of attending a data sharing event, most respondents said that they would participate in another citizen science project. One participant got their whole family involved, and found the project to be 'fun and engaging'. In addition, when asked if they have anything in their daily routine related to environmental action, protection, or stewardship, the most frequent response across both groups was agriculture and gardening. Nearly all participants engage in activities related to environmental protection, which may contribute to the feeling that they can create change in their communities.

Knowledge

For those who attended the report back meetings, the primary definition given for environmental monitoring in the one-on-one interviews was observing the environment, with participants saying that environmental monitoring was 'checking the air and soil and other kinds of natural environments', followed by checking the safety of the environment for human use, such as 'trying to see if the soil has any contaminants that you might ingest from the produce that you're growing'. For those who did not attend, observing the environment was also the primary definition, with participants saying that it was 'observing changes in your environment season after season, watching for disruptions or alterations'. These definitions were compared to a standard environmental monitoring definition of 'the observation and study of the environment' (Artiola, Pepper, & Brusseau, 2004). There were no major differences observed between those who attended and those who did not, although those who attended the data sharing event stated that they felt like they understood environmental monitoring and quality better due to Gardenroots, and that they learned about contaminants in the environment, citing that the sample collection process contributed to this (N=5).

Functionality of data visualizations

When participants were asked about the functionality of the data visualizations, ten of the participants stated the design was functional and that they could find the information they were seeking in their booklet. Participants commented that the booklet was visually appealing (n=1), easy to understand (n=2), well-organized, and had a nice paper weight and quality (n=1). The participants enjoyed viewing their personalized reports (n=2) and comparing their values to the county data and reference values all in one graph (n=3). Although the majority of participants enjoyed the design and functionality of the booklet, many expressed that it contained a lot of information they would need additional time to look over and digest before fully comprehending the material (n=5). One participant stated, ‘I’m definitely going to take [the results booklet] home and … look at it in much more detail and share it with my husband and my friends.’ Two of the participants believed the design was not functional due to the complexity of information. They indicated that the scientific material needed to be simplified further for a layperson to extract useful information.

When considering if the participants had a preferred graphic method, three participants stated that they preferred the graph, two participants liked the table better and three participants said they enjoyed both. The reasons given for favoring the graph over the table was that it was more visual (n=2) and was easier to immediately comprehend (n=3). They also stated that the graph was better for comparison with reference values (n=1) and viewing individual results more distinctly in relation to those values (n=1). The participants who preferred the table over the graph indicated they were more familiar with the table format (n=1) and enjoyed looking at the raw data more (n=1). Those who liked viewing both formats (n=3) specified that they enjoyed the variety of visual communication formats, the thoroughness and detail (n=1) and that both methods were ‘fun to look at’ (n=1).

Elements of the design that needed improvement were related to desired personalized plant data instead of visualizing the county’s data together (n=2), simplifying the plant table so that it was not overwhelming visually (n=1), and utilizing color in the plant table by mirroring the use of color in the soil and water graphs (n=1).

Further comments were made in regards to the graphs as well. The logarithmic scale did not effectively show the variation of numbers in the graphs, as stated by one participant.

> ‘I had trouble reading the graphs. What was interesting to me was when I looked at the raw numbers [numerical value listed in table] because of the correlation of the graph, it didn’t really show you the difference. Like for example, the soils. I had lead at 10 and 16 between garden and yard…the graph didn’t show that.’

When asked about visual improvements in the booklet, participants mentioned the ‘Lifetime excess cancer risk’ figure (Figure 7) (n=5). Four of the participants stated that the figure was too complicated. One participant commented ‘this stuff was added information that I wasn’t really ready to digest tonight… so it probably caught me a little off guard and it was outside the scope of what I anticipated.’ Another participant advised to take off the low and high values, since they were instructed to pay attention to the highlighted median column. Including the low/high values confused the participant and was not perceived as necessary information to know. Lastly, two participants stated there was nothing that needed improvement.

When asked if the participants had anything to add, questions were raised pertaining to vegetable uptake (n=2). ‘If you have heavy metals, are there some vegetables that take it up more readily than others?’ There was also dialogue about the desire for a map or some sort of spatial representation of the data (n=2). ‘That would be interesting to see where the samples, exactly where the samples came from…if we could [see] samples from the northern part of the county, that would be most interesting to me.’ One participant indicated that having the larger 11”x17” copy of the plant table separate from the booklet would help them disseminate the information better to family and friends.

Discussion

Motivation:

In both group and one-on-one interviews, the primary motivation for participation in the program was health concerns. The public was worried about how contaminants in their soil, water, and plants would affect their health. In the interviews for both those who attended the data sharing events and those who did not, expectations of the project were similar and dealt with concern over soil, water, and plant quality. Motivations related to health concerns were common, as participants were worried about how they might be affected by potential contamination. In citizen science studies where participants are not stakeholders, primary motivations tend to stem from interest in the subject or a desire to contribute, while health concerns tend to be the primary motivator for studies where the participants fear their well-being is at stake (Dickerson et al., 2004). This relates to the findings in the pre- and post-surveys, where although there were few significant changes in motivation from the pre- to the post-surveys, participants were mostly internally motivated, rather than externally motivated. In contrast, the external motivation statement that participants most agreed with was: I protect environmental quality or help solve environmental quality problems ‘Because I’m concerned about what could happen to people I care about if I don’t do anything’.

Regarding what motivates participants to be involved in environmental action in general, there is little difference between those who attended the data sharing events and those who did not. This was expected since the report back meetings were not meant to address motivation but simply to share findings. However, whether expectations are met or not is an important factor in whether participants will be motivated to participate in future projects (Wright, Underhill, Keene, & Knight, 2015). Those who attended the report back meetings felt more like their expectations were met than those who did not. This is likely because the report back meetings explained how to interpret the results of the study and how to make informed decisions with the newfound knowledge. When participants attended the data sharing events, they had more contact with the researchers doing the sample analyses, could ask questions, understand the background of the researchers, and have their views heard. The participants were especially pleased with the level of communication and information sharing, with one participant saying ‘it was real clear because of the communication from start to finish’ and ‘it’s something beneficial to us here’, and others saying that it was ‘insightful’ and that they ‘really felt like [they] were contributing’.

Efficacy:

There was no change in efficacy from the pre- to the post survey. This was likely due to the small sample size, as there were fewer people who attended the report back meetings and completed the post-survey. Despite this, all group interview respondents felt that they were more likely to be involved in environmental action after participation in the Gardenroots program. They felt that they could create change in their communities, nearly all said that they would do another citizen science project again. Once the participants saw themselves contributing to a program about the environment they could visualize themselves creating change, especially with the new knowledge they gained (e.g. site-specific data about their immediate environment) (Stajkovic, 1979; Minkler & Wallerstein, 2010). Increases in efficacy are important, as they may lead to increasing behaviors like political participation and communication between volunteers (Overdevest, Orr, & Stepenuck, 2004).

Another reason for the increases in efficacy seen in the group interview participants is the community-first reporting. Group interviews took place after data sharing events, where the participants experienced community-first reporting. The increase in self-efficacy can result from this, as this style of reporting helps to make connections with the community and spur direct action (Emmett and Desai, 2010). This style of reporting allows the participants to bring up solutions of their own, ones that may be more applicable to their lifestyle (Emmett et al., 2009). The communicators examined the social context of the contamination, such as whether people felt in control, and if they had confidence in the institutions doing the informing (Cox & Pezzullo, 2016), and the participants were given the tools to judge the risks for themselves.

Knowledge:

The interview respondents, both those who attended the data sharing events and those who did not, generally reported that they understood environmental monitoring and quality better due to participation in the Gardenroots program. These two respondent groups defined environmental quality similarly to each other, with both providing definitions close to the reference definition. This may be because there was constant communication between the laboratory and the participants. This helps the participants understand the process of environmental monitoring and what goes on in a real laboratory during sample preparation and analysis (Minkler & Wallerstein 2010).

Though there was a low number of interviews completed, minor knowledge differences in responses were observed between those who attended the data sharing events and those who did not. For example, those who attended the data sharing events felt they learned about contaminants in the environment. For those who attended and felt that they learned, it may have been due to the communicator who built both credibility and empathy with the participants. The communicator made sure that the message was relevant to the participant's interest and addressed their concerns, rather than coming in with their own agenda (Renn and Levine, 1991; Scammell, Senier, Darrah-Okike, Brown, & Santos, 2009).

Functionality of data visualizations:

By evaluating data visualization methods used in the Gardenroots Results booklet, we can determine whether design enhances ones' experience in a citizen science program and/or increases a participant's motivation, knowledge, and action. This study gives us insight into gains from the information designs, in what areas participants felt the visuals could be improved, and what features could be added when creating functional data visualization to inform environmental decision-making. The majority of participants found the booklet design to be functional and overall, participants enjoyed the variety of data report back strategies used in the booklet. The aggregated visual aid where the user is able to compare their household data to reference values and other study participant's data received positive feedback due to the readability and data points of comparison. This positive response had been observed in other communities participating in report-back efforts (e.g. Brody et al., 2014, Ramirez-Andreotta et al., 2016a; Boronow et al., 2017).

Visual representations of data will not be translated uniformly for all participants, so it is crucial to measure how the community interprets the graphic information and what changes could be made to increase participant's understanding. Safeguards against misrepresentation are essential to the validity of the data visualization field (Daniel, 1992). For example, a participant felt that the logarithmic scale did not effectively show the variation of numbers in the graphs. This observation notes how the participants' perception of their data is largely related to the scale of the graph and if the values appear close to each other. Using logarithmic scales may have skewed how the values appeared in relation to each other, altering data comprehension by Gardenroots participants. Depending on the number of contaminants measured and the range of data points, the size and number of contaminants depicted in one graph could affect participant comprehension.

Figures were deemed more effective if they were simplified as much as possible and only showing information that is pertinent for the participants to know and within the scope of what they expected. In this study, Gardenroots participants would have preferred a table that showed them only their vegetable data versus the ranges observed throughout their county. In contrast, past Gardenroots participants in Dewey-Humboldt, Arizona received their individual results with the exact amount that can be consumed at their garden (Ramirez-Andreotta et al., 2015). After receiving their individual data, they requested (and eventually received) a summary of results to see the data across all participants. In this study, there were significantly more participants (54 versus 25) and samples, making it challenging to create a personal booklet for each participant. This feedback and comparison highlights how time-consuming data sharing efforts can be, but how critical and worthwhile they are for participants and researchers (Boronow et al., 2017).

Additional requests were made to view results spatially on a map or other geographic representation to compare chemical concentration by region (this could also function through an online experience). This was also noted by participants in other studies who advocated for a map (Ramirez-Andreotta et al., 2016b). Though a map may be helpful, other participants of studies might not want their data shown and there may be future unintentional consequences to generating a map (e.g., financial, decrease in property value) beyond the study. Silent Spring Institute's Digital Exposure Report-Back Interface can potentially reduce practical barriers to high-quality report-back and could address issues related to scaling, time, and access, while providing a platform for comparative analysis of individual-level biomonitoring data and environmental exposures (Boronow et al., 2017). Though the numbers are small, participants who attended the data sharing events felt they learned about contaminants in the environment, more so than those who did not attend; perhaps a digital interface could have successfully addressed the learning needs of those who could not attend the community gatherings.

Limitations

A limitation of this project was the time delay between the collection of samples and data sharing events. Participants were trained in June and they submitted samples between August – October of 2015. The data sharing events across the three counties were held in December of 2016, over a year later. Following the framework of Emmet and Desai (2010), the team reported the data as soon as they were comfortable doing so, but due to a laboratory closure, this was later than anticipated. Participants have wanted their results quickly and within a relevant timeframe, so that they may change their behavior accordingly (Hoover, 2016). These limitations likely impacted attendance to the data sharing events, which then greatly impacted the sample size for survey and interviewee responses, which was much smaller than anticipated.

Conclusion

For those who live near active and legacy resource extraction sites, potential exposure to contaminants of concern can be worrisome. This study was meant to address these concerns by demonstrating the outcomes of a PPSR exposure science program. Through a mixed methods approach, it is clear that the combination of public participation, information design, and face-to-face community reporting with a trusted researcher helps address information disparities in rural communities. Though the participant numbers in the post-assessment activities were lower than desired, this study does report an increase in participant knowledge and efficacy, while also evaluating what motivates a participant to engage in an environment health research project. It also demonstrates how critical the two-way dialogue is between researchers and the affected community.

This work could be taken further by investing more in recruitment efforts to data sharing gatherings and understanding why participants did not participate in some phases of the project, providing multiple platforms (e.g. in-person and online) for participants to interpret and interact with the data and completing a follow-up with Gardenroots participants beyond three months. Overall, the extensive data sharing efforts via information design and face-to-face community reporting with a trust researcher can help build capacity in communities and inform decision-making. This is applicable to all populations, but especially underserved communities.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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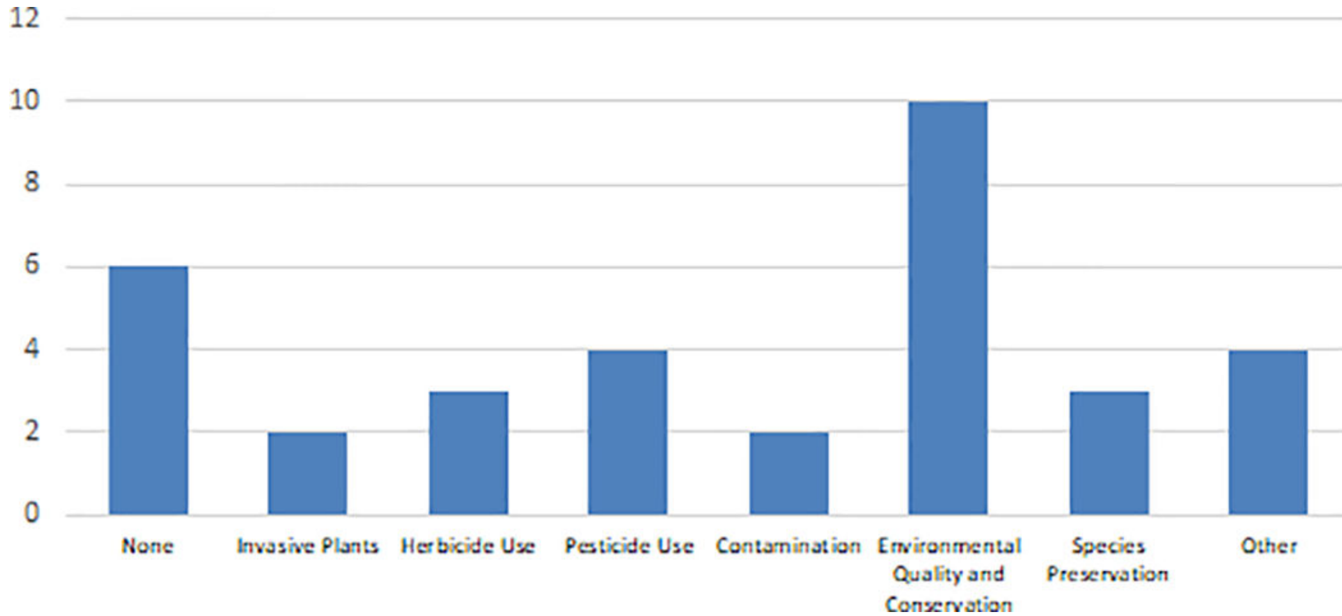


Figure 1:
Community Concerns Regarding Soil, Water, and Plant Quality

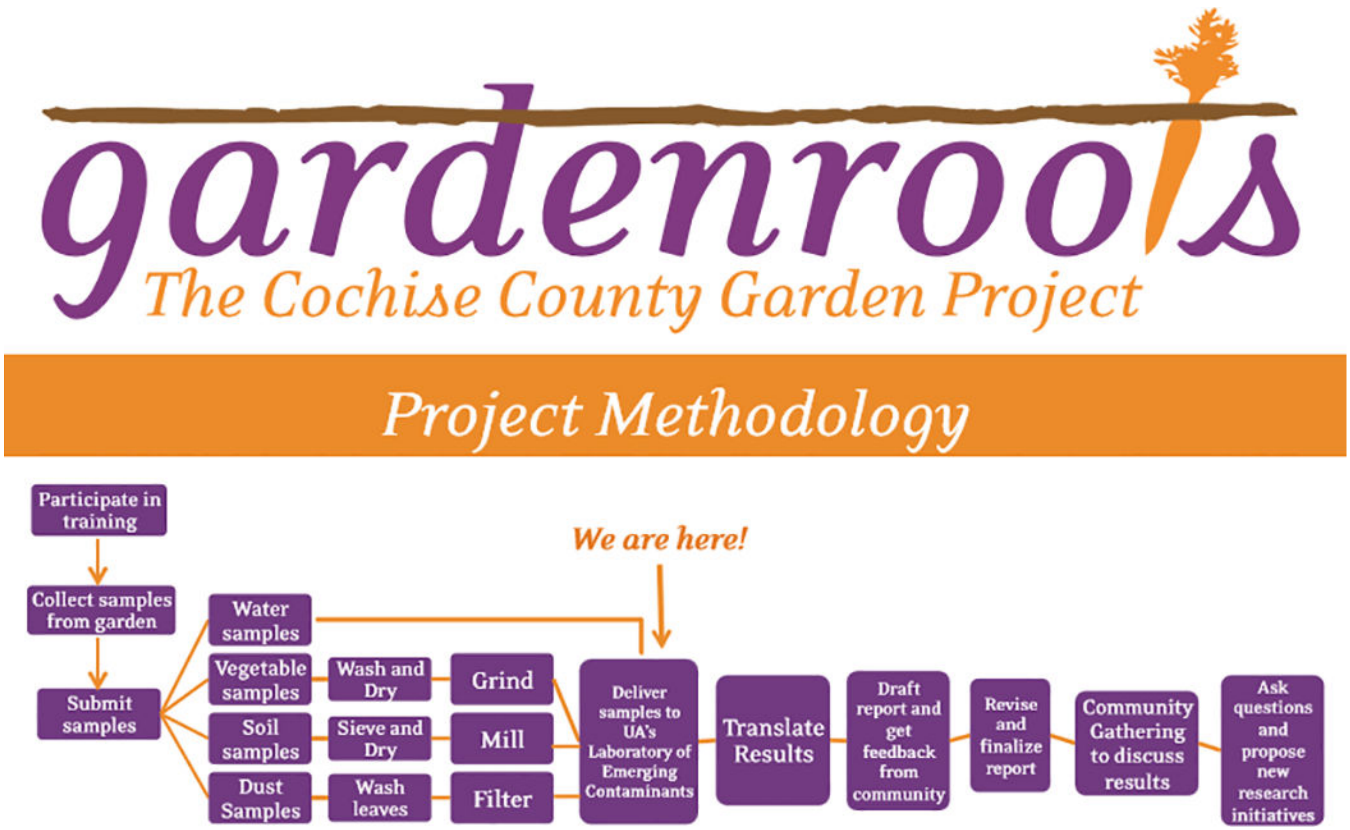


Figure 2:
Update Example

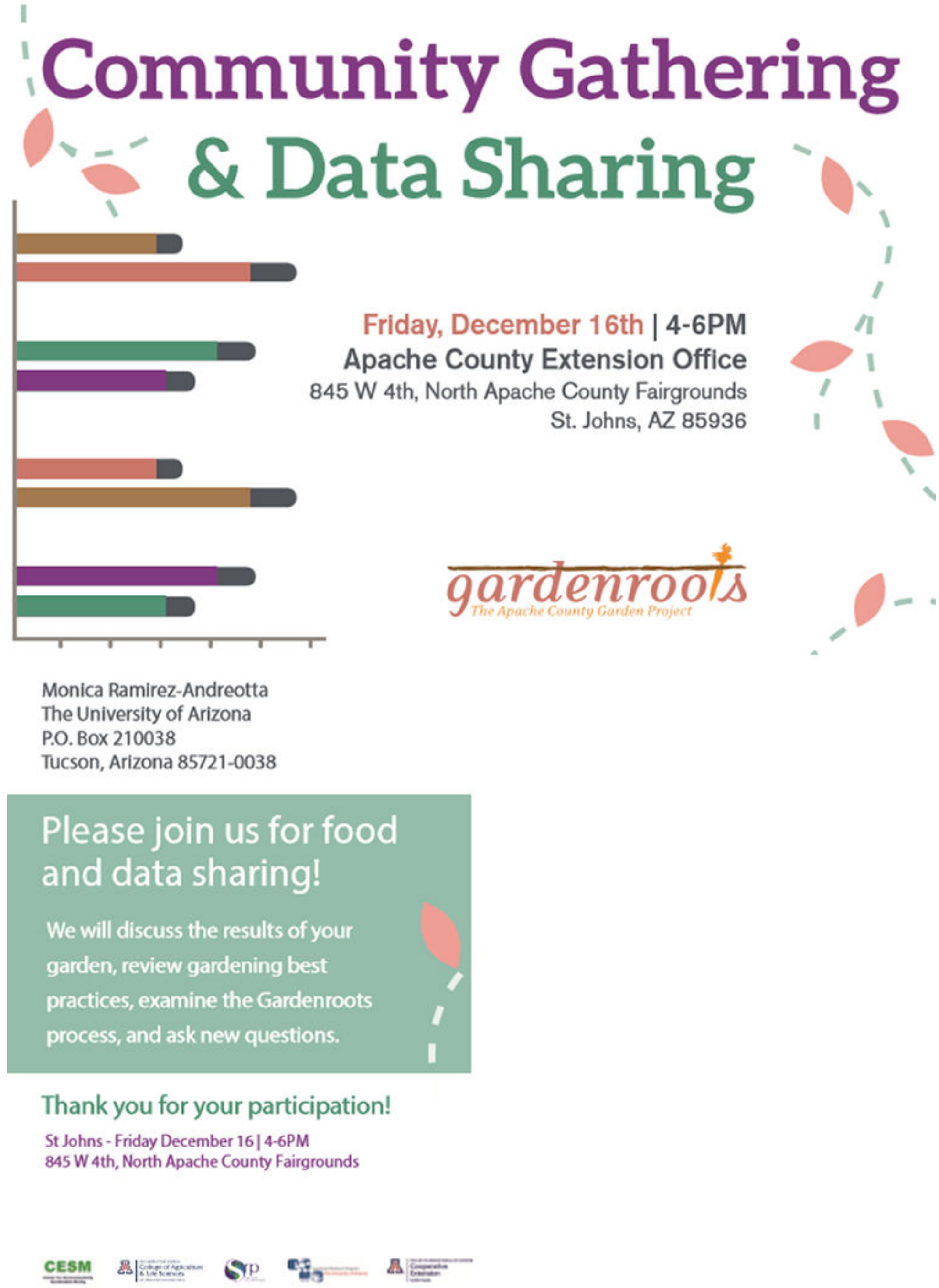
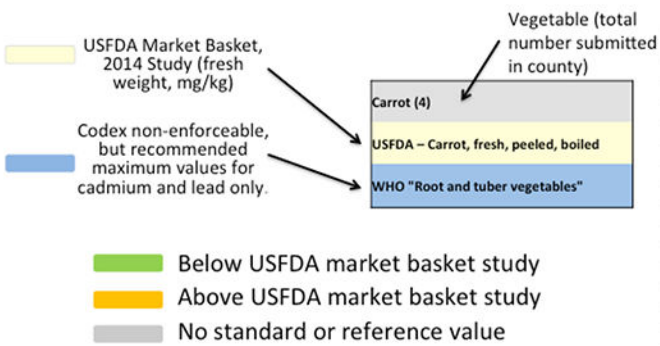


Figure 3:
Data Sharing Events Flyer



Vegetable	Arsenic, total (As)	Cadmium (Cd)	Chromium (Cr)	Lead (Pb)
Arugula (N=2)	0.0506	0.5858	0.0905	0.0708
USFDA did not sample				
WHO "Leafy vegetables"		0.2		0.3
Broccoli raab leaf (N=1)	0.0632	0.526	0.0275	0.0144
USFDA –Broccoli, fresh/frozen, boiled	0.005*	0.008	not analyzed	0.0035*
WHO "Brassica vegetables"		0.05		0.1
Brussel Sprout (N=1)	0.0183	0.0391	0.0438	0.0037
USFDA – Brussel Sprout	0.005*	0.006	not analyzed	0.0035*
WHO "Brassica vegetables"		0.05		0.1
Carrot (4)	0.017	0.025	0.1353	0.044
USFDA – Carrot, fresh, peeled, boiled	0.005*	0.013	not analyzed	0.0035*
WHO "Root and tuber vegetables"		0.1		0.1
Corn (1)	0.008	0.010	0.0689	0.008
USFDA –Corn, fresh/frozen, boiled	0.005*	0.003	not analyzed	0.0035*
Cucumber (N=5)	0.029	0.002	0.0046	0.004
USFDA – Cucumber	0.013	0.002	not analyzed	0.0025*
WHO "Fruiting Vegetables"		0.05		0.05
Green Beans (N=5)	0.006	0.002	0.0222	0.0032
USFDA – Green Beans	0.005*	0.001*	not analyzed	0.0035*
WHO "Legumes"		0.1		0.1

Figure 4:
Plant Sample Data Table Included in Results Booklet

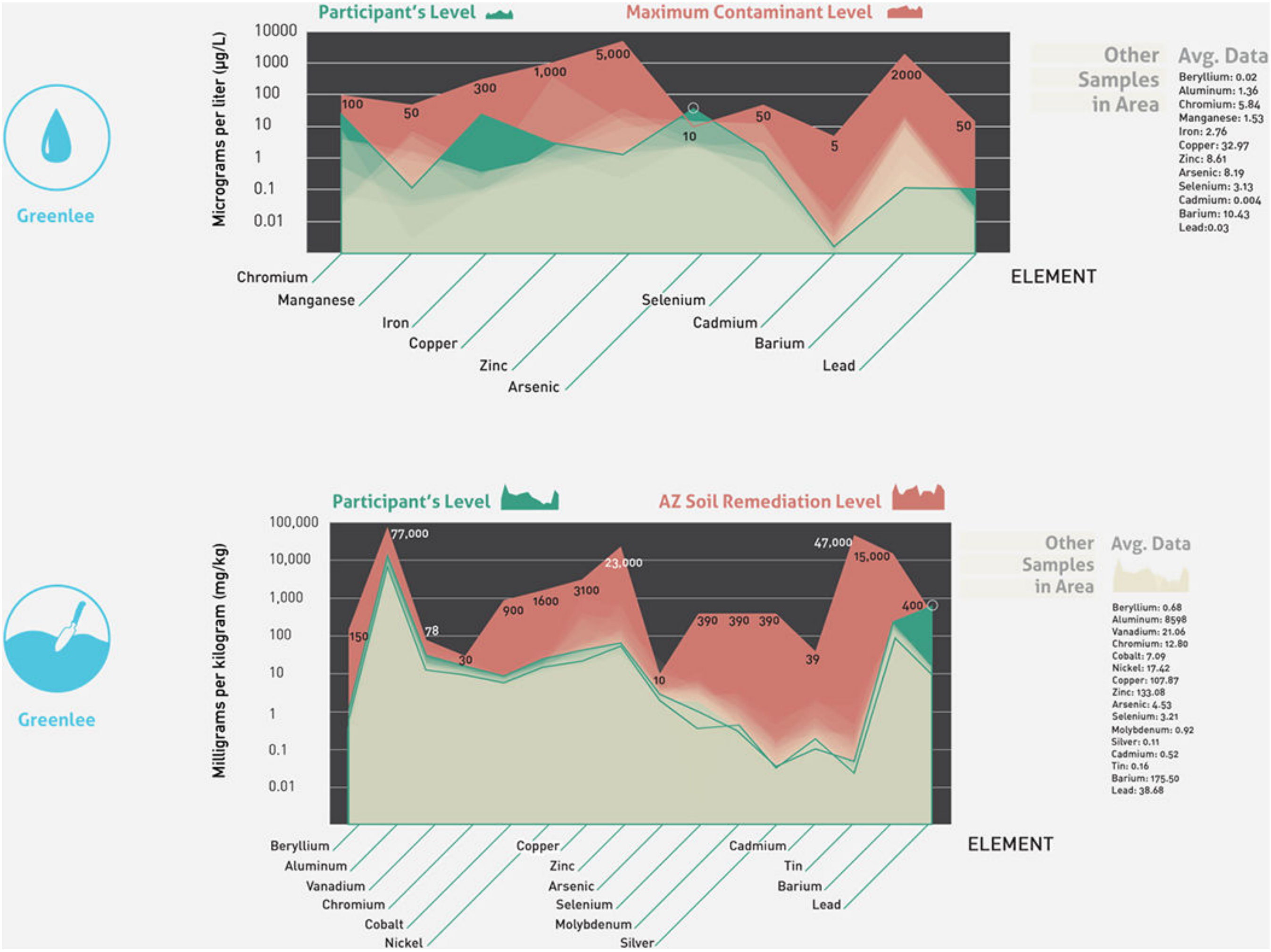


Figure 5:
Water and Soil Sample Data Figures Included in Results Booklet

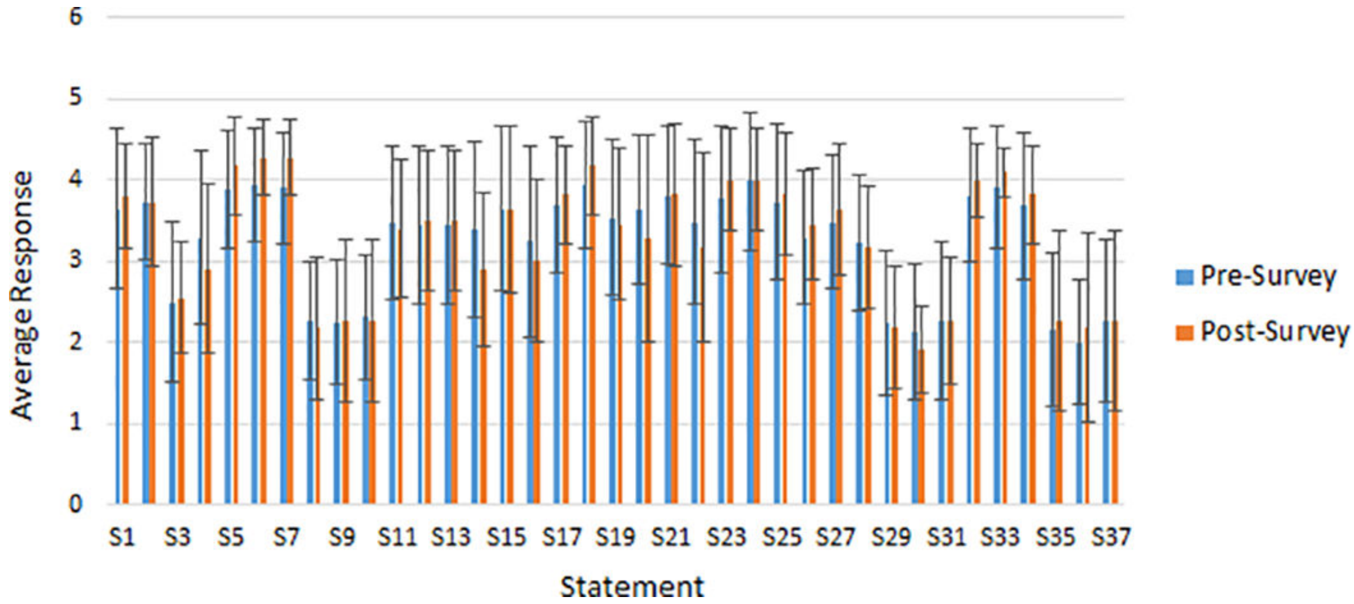
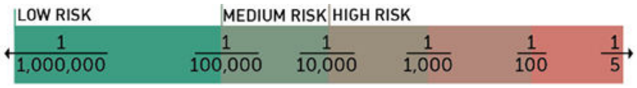


Figure 6:

Means and Standard Deviations for All Self-Efficacy Statements



BDL = Below Maximum Detection Level

Amount you can eat from your garden based on an increased excess lifetime cancer risk due to arsenic exposure

Vegetable	Increased Excess Lifetime Cancer Risk 1/1,000,000			Increased Excess Lifetime Cancer Risk 1/100,000			Increased Excess Lifetime Cancer Risk 1/10,000			USDA Recommended for a female 51+ yrs old (cups/week)	USDA Recommended for a male 51+ yrs old (cups/week)
Concentration	Low Arsenic	Median Arsenic	High Arsenic	Low Arsenic	Median Arsenic	High Arsenic	Low Arsenic	Median Arsenic	High Arsenic		
Asparagus (N=1)		2.2			22			220		3.5 cups per week of "other vegetables"	4 cups per week of "other vegetables"
Beets (N=2)		2			2			1		4 cups per week of "red and orange vegetables"	5.5 cups per week of "red and orange vegetables"
Broccoli (N=2)	0.6	0.4	0.3	6	4	3	64	37	26	4 cups per week of "red and orange vegetables"	5.5 cups per week of "red and orange vegetables"
Carrot (N=1)		0.2			2.1			21.3		3.5 cups per week of "other vegetables"	4 cups per week of "other vegetables"
Cucumber (N=3)		1.0			0.7			0.4		4 cups per week of "red and orange vegetables"	5.5 cups per week of "red and orange vegetables"
Green or wax beans (N=5)	3	2	0	33	17	3	327	171	29	3 cups per week of "raw leafy greens"	3 cups per week of "raw leafy greens"
Lettuce (N=1)		0.003			0.030			0.30		3.5 cups per week of "other vegetables"	4 cups per week of "other vegetables"
Mixed Apple (N=1)		0.48			5			48		3.5 cups per week of "other vegetables"	4 cups per week of "other vegetables"
Okra (N=2)		3			2			1		4 cups per week of "red and orange vegetables"	5.5 cups per week of "red and orange vegetables"
Onion (N=3)	5.0	0.4	0.1	49.8	3.8	0.9	497.6	38.4	9.3	1.5 cups per week of "dark green vegetables"	1.5 cups per week of "dark green veg-etables"
Peach, white (N=1)		0.12			1.2			12		3.5 cups per week of "other vegetables"	4 cups per week of "other vegetables"
Pepper (N=6)	10.3	1.2	0.5	103	11.5	5.5	1034	115	55	3.5 cups per week of "other vegetables"	4 cups per week of "other vegetables"
Pumpkin (N=1)		0.18			1.8			18		1.5 cups per week of "fruits"	2 cups per week of "fruits"
Squash (N=3)	5	0.6	0.0	47	6	0	466	58	4	1.5 cups per week of "fruits"	2 cups per week of "fruits"
Strawberry (N=2)	28.1	0.22	0.11	281	2	1	2805	22	11	1.5 cups per week of "fruits"	2 cups per week of "fruits"
Tomato (N=14)	BDL	5.5	0.050	BDL	55.1	0.5	BDL	551.4	5.0	1.5 cups per week of "fruits"	2 cups per week of "fruits"
Watermelon (N=1)		0.9			9			90		1.5 cups per week of "fruits"	2 cups per week of "fruits"

It is your choice to decide what target risk you want to use to make decisions about how many cups per week to consume from your garden.

Figure 7:
Excess Lifetime Cancer Risk Based on Arsenic Concentrations in Plant Samples

Table 1:

Number of Participants in Activities

County	***Community members trained***	***Pre-Survey Completed***	***Samples submitted***	***Attended Data-Sharing Events***	***Post-Survey Completed***	***Group Interviews***	***Interviews***
Apache	21	3	8	2	2	2	2
Cochise	42	26	34	12	12	8	8
Greenlee	31	20	21	3	2	2	4
Totals	94	49	63	17	16	12	14

Table 2:

Contents of Results Packet Provided to Participants

1	Project Overview –Narrative describing the study and key information about the Gardenroots project design (2 pp.)
2	List of Important Terms (2 pp.)
3	Results, divided into: Water (4 pp), Soil (4 pp), and Plant (10 pp., plus a 11×17 print out of county plant data), each containing the following sections: • Understanding Your Results • Data figures showing the participant's environmental sample in comparison to existing standards (U.S. EPA maximum contaminant levels in drinking water, AZ Department of Environmental Quality -ADEQ soil remediation levels) and reference values for vegetables (U.S. Food and Drug Administration's Market Basket Study and/or World Health Organization's Codex Alimentarius)
6	Information on nine contaminants of concern (e.g. What is Arsenic? What happens to arsenic when it enters the environment? How might I be exposed to arsenic? How can arsenic effect my health? – 9pp.)
7	References for all values used and list of websites to visit for more information (e.g., Agencies for Toxic Substances and Disease Registry Toxicological Profiles, ADEQ, US EPA – 2 pp.)
8	A section to take notes during the training
9	Separate one-page best practices handouts on: • Garden Preparation: Reduce Arsenic Absorption by Vegetables • Safe Gardening: Reduce Incidental Soil Ingestion and Inhalation • Safe Consumption of Homegrown Vegetables: Reduce Dietary Arsenic and Lead Ingestion

Table 3:

Group Interview Responses

Topic	*Question*	*Response*
Motivation	***What were your reasons for participating in Gardenroots?***	Concern for health (n = 9)
		Education or learning (n = 4)
		Evaluating or growing food (n = 4)
	Did you feel like you could see how you were contributing to the study?	No (n = 0) Yes (n = 10)
Efficacy	***Do you feel like you are more, less, or equally likely to be Involved in environmental action in your community as a result of Gardenroots?***	Less (n = 0) Equally (n = 0) More (n = 9)
	Do you feel like you are capable of creating change in your community?	No (n = 0) Yes (n = 13)
	Would you do another citizen science project? Why or why not?	No (n = 0) Not presently (n = 1) Yes (n = 10)

Table 4:

One-on-One Interview Responses

Topic	*Question*	*Attendee Responses*	*NON-Attendees Responses*
Knowledge	***What is environmental monitoring?***	Observing the environment (n = 4) Checking safety of environment for use (n = 2) Environment is everything (n = 1)	Observing the environment (n = 4) Checking safety of environment for use (n = 1) Monitoring natural elements (n = 1) Baseline measurements plus other factors (n = 1)
	Did you feel like you understand environmental monitoring and quality better as a result of Gardenroots?	Yes (n = 4) No (n = 1) It was a new topic (n = 1) I had prior knowledge (n = 1)	Yes (n = 4) No (n = 3)
	After Gardenroots, did you feel like you learned about contaminants in the environment?	Yes (n = 4) No (n = 2)	Yes (n = 3) No (n = 3)
	Now that you have your results, do you see your surrounding environment differently?	No (n = 3) Yes (n = 4)	No (n = 3) Yes (n = 2) Not applicable (n = 2)
Motivation	***Did you feel like you could see how you were contributing to the study?***	No (n = 0) Yes (n = 7)	No (n = 0) Yes (n = 7)
	Do you feel like your expectations were met?	Yes (n = 5) No (n = 1) None (n = 1)	Yes (n = 3) No (n = 4) None (n = 1)
	What did you anticipate you would get out of this experience?	Soil condition (n = 5) Plant condition (n = 3) Water condition (n = 4) Best practices (n = 1) General information (n = 1)	Soil condition (n = 3) Water condition (n = 2) Best practices (n = 2) General information (n = 2) Contribute to project (n = 1) Not applicable (n = 1)
	What did you get out of this experience?	Results for soil, water, plant condition (n = 5) Feeling of contribution (n = 1) Pollution source information (n = 1)	Results for soil, water, plant condition (n = 3) Sense of community (n = 1) General Information (n = 3)
	What motivates you to be involved in environmental action? This could be personal goals, or caused by an event or moment.	Being asked to (n = 1) Concern for future generations (n = 1) Environmental preservation (n = 4) Not able (n = 1)	Care for food and its importance (n = 2) Creating a better environment now (n = 1) Environmental preservation (n = 2) Respecting nature (n = 1) Rural experience (n = 2)
Efficacy	***Would you do another citizen science project?***	Not able (n = 1) Yes (n = 6)	No (n = 1) Yes (n = 6)
	Do you have anything in your daily routine that is related to environmental action, protection, or stewardship?	Agriculture/gardening (n = 4) Minimizing environmental impact (n = 1) Recycling (n = 2) Running environmental programs (n = 1) Water conservation (n = 2) None (n = 1)	Agriculture/Gardening (n = 4) Running Environmental Programs (n = 2) Water Conservation (n = 1) None (n = 1)
Other	***If you were to describe the Gardenroots program to your friends or family, how would you describe it?***	Citizen participation (n = 3) Learning what is in soil/water/plants (n = 4) Personalized Results (n = 2)	Citizen participation (n = 4) Educating yourself (n = 1) Government monitoring pollution (n = 1) Learning best practices (n = 2) Learning what is in soil/water/plants (n = 2) Positive experience (n = 1) University program (n = 1)