In: Public Health
Editors: Rosemary M. Caron and Joav Merrick

ISBN: 978-1-63321-569-6

Chapter 15

Building a co-created citizen science program with gardeners neighboring a superfund site: The Gardenroots case study

Monica D Ramirez-Andreotta, MPA, PhD[1*], Mark L Brusseau, PhD[1,2], Janick F Artiola, PhD[1], Raina M Maier, PhD[1] and A Jay Gandolfi, PhD[3]

[1] Department of Soil, Water and Environmental Science
[2] Department of Hydrology and Water Resources Department
[3] Department of Pharmacology and Toxicology, The University of Arizona, Tucson, Arizona, US

A research project that is only expert-driven may ignore the role of local knowledge in research, give low priority to the development of a comprehensive communication strategy to engage the community, and may not deliver the results of the study to the community in an effective way. Objective: To demonstrate how a research program can respond to a community research need, establish a community-academic partnership, and build a co-created citizen science program. Methods: A place-based, community-driven project was designed where academics and community members maintained a reciprocal dialogue, and together, we: 1) defined the question for study, 2) gathered information, 3) developed hypotheses, 3) designed data collection methodologies, 4) collected environmental samples (soil, irrigation water, and vegetables), 5) interpreted data, 6) disseminated results and translated results into action, and 7) discussed results and asked new questions. Results: The co-created environmental research project produced new data and addressed an additional exposure route (consumption of vegetables grown in soils with elevated arsenic levels). Public participation in scientific research improved

[*] Correspondence*:* Assistant Professor Monica D Ramirez-Andreotta, MPA, PhD, Department of Health Sciences, Bouvé College of Health Sciences Northeastern University, 360 Huntington Avenue, 336INV, Boston, MA 02115, United States. E-mail: m.ramirezandreotta@neu.edu.

environmental health assessment, information transfer, and risk communication efforts. Furthermore, incorporating the community in the scientific process produced both individual learning outcomes and community-level outcomes. Conclusions: This approach illustrates the benefits of a community-academic co-created citizen-science program in addressing the complex problems that arise in communities neighboring a contaminated site. Such a project can increase the community's involvement in risk communication and decision-making, which ultimately has the potential to help mitigate exposure and thereby reduce associated risk.

List of acronyms

USEPA	US Environmental Protection Agency
NPL	National Priorities List
CBPR	Community based participatory research
PPSR	Public participation in scientific research
UASRP-RTC	University of Arizona Superfund Research Program Research Translation Coordinator
NIEHS	National Institute of Environmental Health Sciences
UA	The University of Arizona
ADEQ	Arizona Department of Environmental Quality
Iron King	Iron King Mine and Humboldt Smelter Superfund Site

Introduction

Typically community members living in contaminated communities are the ones who initially identify adverse ecological and health outcomes associated with toxic exposures (1), although a state agency, regional US Environmental Protection Agency (USEPA) office, or the responsible party may also make this discovery. The USEPA may add the site to the Comprehensive Environmental Response, Compensation, and Liability Information System, which can lead to a cascade of regulatory and/or remedy events. For example, sites on the National Priorities List (NPL) with groundwater contamination, the time from discovery to remedy implementation can go beyond 20 years, and long-term management (i.e. decades to centuries) is needed at many sites (2). As time passes, site managers are responsible for monitoring the progress of remediation and engaging the community to inform them of the cleanup progress and describe potential risks associated with the site.

Traditionally, site managers engage the community in a one-way communication model that solely aims to inform, change behavior, and assure populations that the determined risk is acceptable and that cleanup is underway (3, 4). This communication strategy has a low rate of success, primarily because it excludes those most affected (3) and fundamentally does not aim to increase environmental education or involve the community in the decisions about their risk. Historically, because communities were not involved in the decision-making process, mistrust often eroded the relationships between scientists, regulatory officials, and the affected communities (5,6).

The lack of public participation at contaminated sites is a great loss, as community members have been contributing to science since the 17th century (7, 8) and in general, volunteerism is considered critical to civic life in the United States (9,10). Volunteers have monitored watershed health in more than 700 programs in the US, involving over 400,000 local stakeholders (11) and most ecological research once fostered public participation in most or all of the steps in the scientific process (8). However, due to the professionalization of science, the role of the amateur scientist has diminished (8). The value of public participation in addressing environmental and health issues has received renewed attention in the past couple of decades through efforts such as public participation in scientific research (PPSR)/ citizen science (12), community based participatory research (CBPR) (13), popular epidemiology (14), and street science (15).

Public participation in scientific research, often termed citizen science, is a form of informal science education, and is broadly defined as a partnership between scientists and non-scientists in which authentic data are collected, shared, and analyzed (12,16,17). Citizen science projects are meant to increase a participant's scientific literacy (12), to collect field data to monitor a variety of environmental conditions (7), and as a framework to support and enhance decision-making in modern society (17,18). Previous research in science education and sociology has demonstrated the need to engage communities in scientific research and that this level of engagement can be successfully facilitated via community-academic partnerships. Members of a community neighboring a contaminated site are typically intrinsically motivated to learn more about the site and in most cases, have already begun to gather additional scientific data and hypothesize other potential routes of exposure and areas that need additional monitoring. Research related to inquiry-based education has elucidated how people have a greater motivation to engage and learn when the subject matter is directly related to their lives and if the learning process is interactive (19). Popular epidemiology, a community-driven practice, was proposed after observing the activities of communities experiencing contamination and entails community initiation of investigations, gathering of scientific knowledge, and, if necessary, recruiting of scientific professionals (14). "Street Science" is an approach for environmental health justice that joins local knowledge with professional techniques, re-values forms of knowledge that professional science has traditionally excluded (15).

To date, only a limited number of co-created PPSR projects, which are jointly developed by members of the public and scientists and designed to actively involve community members in most or all steps of the scientific process, have been initiated at contaminated sites and none in conjunction with risk communication as described herein. This paper will outline the methods and activities employed to build a community-academic partnership that resulted in the co-created citizen science project entitled *Gardenroots: The Dewey-Humboldt, Arizona Garden Project* (hereafter, *Gardenroots*). In order to foster PPSR, it is essential to establish a community–academic partnership via a CBPR approach to research, which shares power with community partners in all aspects of the research process and benefits communities via interventions and policy change (13).

The enhanced CBPR approach presented herein is based upon the belief that PPSR in conjunction with CBPR can improve site assessment and risk communication efforts. Public participation can be a vehicle to address concerns regarding environmental contaminants and exposure routes that might not be addressed in a typical expert-only-led site and risk assessment. Lastly, PPSR provides a unique opportunity for informal science education and a way in which for the community may learn more about environmental science, human health research, and risk assessment.

Methods

The *Gardenroots* approach followed recommended CBPR practices (13). The co-created citizen science project will be described in terms of PPSR (see table 1), demonstrating community involvement in most phases of the research (12). The traditional CBPR/PPSR steps have been enhanced and the methods described herein also include: building a transdisciplinary team, bidirectional communication with government agencies, an informal science education learning continuum, and a substantial risk communication component. Lastly, this project received Institutional Review Board approval.

Background

Gardening and consuming edible plants grown in contaminated soils presents a health hazard that may effect home gardeners neighboring contaminated environments. The town of Dewey-Humboldt is in an arsenic endemic region of Arizona and is adjacent to the Iron King Mine and Humboldt Smelter Superfund site (Iron King). The site serves as a persistent source of pollution, introducing a host of potential human-health risks and concomitant risk communication challenges. Such contamination (natural or human-made) can affect humans directly via the inadvertent consumption of soils, through the consumption of crops grown under contaminated conditions, and/or the consumption of contaminated water.

How a research program can respond to a community research need

Beginning in 2007, the University of Arizona (UA) Superfund Research Program Research Translation Coordinator (UASRP-RTC) and the USEPA Region 9 Superfund and Technology Liaison began executing a two-pronged communication mechanism consisting of a webinar hosted by National Institute of Environmental Sciences (NIEHS) and USEPA and a "Live at R9" in-person seminar to foster regional partnerships (20). During a "Live at R9" visit in June of 2007, an USEPA project manager mentioned that an abandoned mining site located in rural Arizona would be added to the NPL and that UA and EPA might be able to assist in some capacity at the site. The USEPA kept the UASRP-RTC up-to-date on the status of the site and on August 3, 2008 the Iron King Mine Superfund site was listed on the NPL. On August 20, 2008, the USEPA organized their first community "Kick-Off Meeting" after the official listing to discuss the Superfund process and that they were initiating the field investigation portion of the Remedial Investigation and Feasibility Study. Forty-six community members, two members of UASRP-RTC, the USEPA Project Manager and Community Involvement Coordinator, a member of the Arizona Department of Environmental Quality, and the Dewey-Humboldt mayor attended the meeting. During the meeting, several community members asked whether the site has impacted their soil and if they may continue to grown vegetables.

At the end of the meeting, members of the Dewey-Humboldt, community specifically asked the UASRP-RTC "Is it safe to garden and consume vegetables from my home garden? And if so, how much can I eat from my garden?" Without any specific data to conclusively answer the question, a representative of the UASRP-RTC, stated that she was interested in this research question as well, and whether they (the people who expressed concern) were interested in participating in a research project. Residents agreed and in less than two years an academic-community partnership came into fruition that took the form of a co-created citizen science project, *Gardenroots*. The goals of the *Gardenroots* project were to bring scientists from various disciplines together within the UA and to work in collaboration with the affected community to: (1) determine the uptake of arsenic in garden vegetables grown by the Dewey-Humboldt, AZ community, and (2) conduct an exposure assessment and characterize the potential risk posed by gardening and consuming vegetables from residential home gardens.

Establishing a community academic partnership

The community members who originally posed the research question and the lead UA investigator became the point of contact and "champions" (21) for the research project within their affiliations. They were persistent, promoted the project, and networked to obtain the involvement of a broader representation of residents in the area. In addition, the UA investigator made a point to maintain a consistent presence in the community by attending town council, USEPA meetings and community events and was in the area at a minimum frequency of once every two months throughout the duration of *Gardenroots*. It was this type of promotion and dedication that truly fused and generated the community-academic partnership. In addition to promotion, continuity is crucial. To date, the RTC continues to maintain bidirectional communication between the community, EPA, Arizona Department of Environmental Quality (ADEQ), Arizona Department of Health Services, and Agency for Toxic Substances and Disease Registry, via teleconferences and meetings to ensure transparency and unified messaging to the community.

Building a research team

A transdisciplinary team was created involving the Dewey-Humboldt community and the UA including researchers in the disciplines of environmental chemistry and microbiology, soils, hydrology, public health, and visual communications. The UA Cooperative Extension Director of Yavapai County was recruited as part of the team to provide home gardening expertise. Interactions with USEPA Region 9 representatives were ongoing to ensure that this research question was aligned with their current research challenges at the Iron King site.

Building a co-created citizen science research program: public participation in environmental research

As stated above, the UA Investigator maintained a consistent presence in the community by attending town council, USEPA and community meetings and events and was frequently in the Dewey–Humboldt area. Through the continuity of community engagement, the UA investigator built trust and learned a great deal about the nuances and idiosyncrasies of the area. This knowledge facilitated implementation of a place-based communication strategy (22) to recruit other community members into *Gardenroots*. The recruitment and design of recruitment and educational materials was informed by the social context and community ecology of Dewey-Humboldt, Arizona. The majority of the recruitment for *Gardenroots* was done via personal interaction at local community events through the following activities:

- Handing out informational bookmarks (Figure 1) at community festivals, EPA community meetings, and Town Council meetings.
- Follow-up mailings, telephone calls and emails to community members
- A County Cooperative Extension Press Release
- An announcement in the Dewey-Humboldt town newsletter
- A website

Front of bookmark

Back of bookmark

Figure 1. Front and back of promotional bookmark distributed at community events to recruit gardeners.

Greenhouse study

Collecting soils from a residential area in Dewey-Humboldt, AZ was fundamental to conducting the controlled greenhouse study. Since the USEPA had already begun the site investigation, members of the community had been given their residential soil results. Based on their results, a community member offered their soils for the greenhouse study and assisted in identifying the appropriate locations to collect soils in their yard based upon the USEPA data and their understanding of the neighboring watershed. In addition, this community member provided detailed historical information regarding their property and areas of interest realted to the Iron King site.

Field study

After all recruitment activities discussed above were completed, those who signed up for *Gardenroots* were asked to attend a 1.5-hour training session wherein they were provided information on how to properly collect soil, water, and vegetables samples from their home garden for laboratory analysis. Two trainings were formally offered and community members that participated in the training took home an instructional manual (Figure 2A) and a tool kit with all supplies required for sample collection from their home garden. Several community members were unable to attend a scheduled training. An additional less formal training was offered and in some instances, kits were personally delivered to community member's homes at their request.

During the five-month period from when participants received their kit and during the Spring/Summer growing season, participants were asked to deliver their samples to the local Cooperative Extension office. The in-person training, designing a user-friendly manual, and collaborating with the local extension office assured sample quality. In the end, participants actively contributed to the field study portion of *Gardenroots*. Table 1 outlines the steps in scientific research, level of public participation, the community's role and benefits, and challenges associated with each step.

Capacity building and continuity

In order to properly and effectively manage community expectation and involvement throughout the entire *Gardenroots* project (from the posing of the research question to the final community report-back events), ongoing communication was maintained via phone, email and mail correspondence, and informal science education experiences were offered. Based upon what the community wanted to learn, and in efforts to further understand their concerns regarding the Iron King site, the *Gardenroots* Learning Continuum was designed to provide participants with responsive, unique, and informal learning opportunities (Figure 2) throughout the course of the *Gardenroots* project. *Gardenroots* culminated in a large report-back gathering "Results for Lunch: Your Soil, Water and Vegetable Outcomes" (Results for Lunch). After the Results for Lunch gathering (Figure 2B), participants requested an overall summary of results and presentations that would be open to the broader community.

Table 1. The components of *Gardenroots*: The Dewey-Humboldt, Arizona Garden Project

Steps in Scientific Research	Participant Participation	Community Roles and Benefits	Challenges Associated with Step
Choose or define question(s) for study	√	• Community members posed research question at the EPA Superfund Site Kick Off Meeting in August 2008	• It took a year to secure funding for the project
Gather information and resources	√	• Community member provided soils for greenhouse study • Yavapai and Pima County Master Gardeners in the area assisted with what to grown in the greenhouse. • Participants were asked to describe how he or she amends their soils.	• Reaching all community members in the area interested in vegetable gardening
Develop explanations (hypotheses)	√	• At trainings, community members developed hypotheses regarding what they expected to observe in their household results and for the entire study. ○ For example, several participants hypothesized that the closer to the tailings a home was, the higher the arsenic concentration would be in the soils.	• Setting and maintaining expectations. It was important to restate goals and what type of data could truly be expected from *Gardenroots*. • Explaining that the number of samples was not sufficient to truly characterize the spatial distribution of arsenic as well as the complexity and uncertainty related to the atmospheric distribution of arsenic. ○ For example, wind direction in the area changes seasonally, the area has naturally occurring arsenic and has been affected by both smelting and mine tailings, which produce different sized particles that can experience different levels of transport by wind.
Design data collection methodologies	√	• Participants decided where to collect soils from their residential property (garden and yard) and what vegetables they wanted analyzed	• Since there was not one predetermined vegetable grown in every garden, it was challenging to compare across households. Regardless, it was important to have participants grow what they wanted to make sure the study was relevant and applicable to everyone. • Explaining that the one area they sampled might not be representative of their entire yard and that arsenic soil concentrations may vary in a relatively small spatial area.

Steps in Scientific Research	**Participant Participation**	Community Roles and Benefits	Challenges Associated with Step
Collect samples and/or record data	√	• Participants collected their soil, vegetable and irrigation samples • Participants labeled all samples	• No major challenges to report.
Analyze samples	x	• Community did not participate in this step, although at community gatherings, analytical methodology was described in great detail	• Due to the nature of the sample analyses and formal laboratory procedures, the participants did not get to prepare their samples via acid digestion or analyze samples via inductively coupled plasma mass spectrometry.
Analyze data	x	• Community did not participate in this step, UA investigator analyzed all the data. • At the "Results for Lunch" and other community gatherings, the methods and mathematical equations used to interpret the data was described in great detail and participants were given the opportunity to recalculate their potential exposure and risk and change the variables to suit their behavior.	• No challenges to report.
Interpret data and draw conclusions	√	• Participants were given the results from their individual soil, water, and vegetable samples, exposure assessment and risk characterization results. • At community gatherings and meetings, the aggregated results were presented	• Determining whether their soil and water arsenic concentrations may be due to naturally occurring and/or from anthropogenic sources like the mine and smelter.
Disseminate conclusions/ translate results into action	√	• Participants shared data with others outside of the *Gardenroots* project • Using their data, participants have translated the results into personal action and have modified their gardening practices.	• Even though *Gardenroots* informed and invited USEPA and ADEQ to all report-back and community events, it was challenging to maintain bidirectional communication between the project and all government agencies working at the site.
Discuss results and ask new questions	√	• At the "Results for Lunch" and other community gatherings, results were discussed in detail, participants compared their results to their neighbors and friends and new questions were posed.	• Since *Gardenroots* was an environmental monitoring project, inquiries regarding potential health outcomes were outside the feasibility of *Gardenroots*. In these cases, the expectations and goals of *Gardenroots* were restated and the inquiries were forwarded to health scientists at the UA.

In response, three additional presentations were given and a "Summary of Results" booklet was generated and distributed to participants and other community members in the Dewey-Humboldt, Arizona area. In addition to the *Gardenroots* Learning Continuum, and as stated in the Field Study section above, participants were actively involved in most steps of the scientific process (Table 1) and this high level of participation was instrumental in building capacity and maintaining continuity.

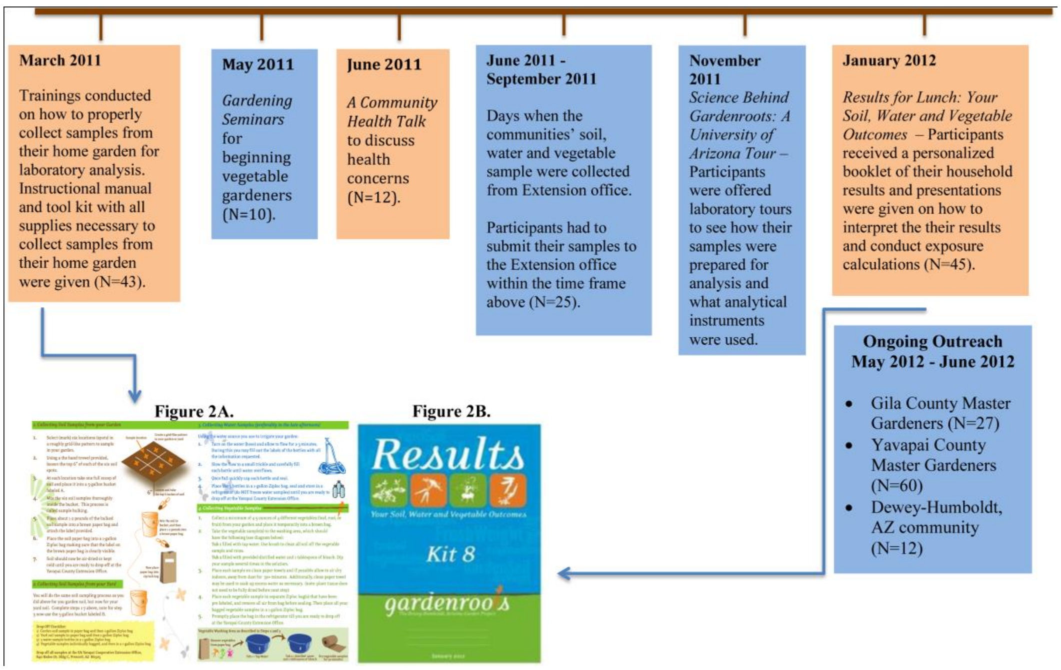


Figure 2. *Gardenroots* Learning Continuum and collection times. The time line demonstrates the activities and co-learning opportunities (N = Number of participants at each event) provided throughout the program.

Risk communication

Once all community samples had been analyzed, results were reported back to the participants to answer questions such as: Can I consume vegetables from my garden? If so, how much is safe? To do this, participants were invited to the Results for Lunch gathering, where they were given an informal presentation on the: 1) methodologies used to prepare and analyze their household samples, 2) exposure assessment and risk characterization calculations used to interpret their data, and 3) an introduction to the format in which their results would be presented. Next, they were given tailored personalized booklets (Figure 2B) that contained the "raw" confidential data (i.e., milligrams of arsenic per kilogram of vegetable) as well as a table that outlined the quantity of vegetables they could consume at various target risk levels compared to the US Department of Agriculture recommended amounts (Supplemental Fig. 1). It is important to emphasize that intake rates based on the site-specific characteristics of their individual garden were calculated for each participant to consider. Additionally, the concentrations observed in the vegetables were compared to the concentrations of arsenic reported in the U.S. Food and Drug Administration Total Diet Study Statistics on Element Results based on the 2006–2008 Market Basket Study. The Market Basket Study involved purchasing samples of food throughout the U.S., preparing the food as it would be consumed, and analyzing the foods to measure the concentrations of selected elements and compounds. This provided a valuable frame of reference and is considered an acceptable risk comparison (5). This reporting method was designed to give participants all the information they requested and allow them to decide for themselves the target risk they wanted to achieve (Table 2).

Table 2. Comparing report-back efforts and what information *Gardenroots* participants were provided throughout the project

Typical participant questions about personal exposure results, Brody et al., 2007	Information provided to *Gardenroots* participants
Description	
What did you find?[1] What did you look for?	Concentration of arsenic (contaminant of concern) and 19 other elements of potential interest
How much?[1]	Concentrations for all 20 elements were presented in a chart for all their vegetables, soil and water samples analyzed.
Analysis/Comparison	
Is that high? [1]	Arsenic concentrations observed in vegetables from the USDFA Market Basket Study were used for comparison. Regional soil screening levels and the maximum contaminant levels in water was provided.
Is that safe?[1]	Chart exhibiting how much of the vegetable can be consumed from their garden at various excess target risks
What should I focus on?	Participants were able to compare the risk posed from each exposure route (water, soil, vegetable) and the arsenic concentration in each vegetable to then decide where to focus mitigation efforts
Where did the chemical come from?	Participants identified their gardens as potential sources of arsenic and initially asked the research question
Recommendation	
What can/should I do?[1]	Exposure reduction/precautionary strategies were provided such as: recommended gardening practices handouts were generated to guide gardeners, "Arizona Know Your Water" and "Arizona Know Your Well Water" guides*

[1]These question were also posed by the Dewey-Humboldt, AZ community in the initial stages and of the study. All report back materials were designed to provide answers to participant's specific questions and coincide with those observed by Brody et al., 2007.

*All handouts and guides were distributed at community gatherings and are available at: and http://www.superfund.pharmacy.arizona.edu/content/informational-materials.

The risk associated with consumption of garden vegetables was also compared to risks associated with other potential exposure routes, such as ingestion of potable water and incidental soil ingestion. It was strongly recommended that home gardeners: sample their private wells regularly, test their soils prior to gardening, and modify their gardening behavior to reduce incidental soil ingestion (23). Based upon these findings, three waterproof handouts were developed to disseminate the recommended behavioral modifications necessary to reduce arsenic exposure from incidental soil ingestion and vegetable consumption (Supplemental Fig. 4, available at http://www.superfund.pharmacy.arizona.edu/content/Gardenroots).

Findings

Forty-three individuals attended the training and received a *Gardenroots* toolkit and instructional manual, 58% or 25 participants actually completed the *Gardenroots* project, and of the participants, 18 completed a survey. Eighty-four percent of the population has some type of education beyond high school, 44% had been living in the area for 8 or more years, and 94% of the participants were Caucasian (Supplemental Table 1). Based on the most recent US Census Bureau, the demographics are reflective of the area, except 28% of the *Gardenroots* participants had a bachelor's degree or higher compared to 13.5% for the general population.

Outcomes

It has been suggested that citizen science learning outcomes can best be evaluated by observing three levels: individual learning, programmatic, and community-level outcomes (24). This is very similar to the evaluation strategies used to report CBPR program successes in the Northern California Household Exposure Study (25) and in 54 National Institute of Environmental Health Sciences funded environmental justice projects (26). Below, we apply this new framework and describe the results and outcomes of the *Gardenroots* project.

Individual learning outcomes – what community members learned and new research questions posed

The results of *Gardenroots* indicated that for the Dewey-Humboldt community mitigating arsenic exposure from potable water and incidental soil ingestion (not even considering vegetable consumption) would significantly reduce daily arsenic intake. The challenge in communicating these results was the fear that the participants, realizing that their water and soil arsenic levels were high, would no longer want to garden or consume vegetables from their garden, regardless of the comparatively low arsenic exposure from their raw vegetables. Fortunately, the majority of the participants stated that they would continue to eat home-garden vegetables, but would modify their gardening practices. This demonstrates that the scientific findings were understood and that the community could put into action behavioral changes necessary to reduce their arsenic exposure from water and soil. This capacity demonstrated by participants is similar to what has been previously reported, where community members demonstrated a capacity to understand and contend with the complexity and uncertainty associated with the results (27).

Analysis of individual learning also showed that *Gardenroots* prompted curiosity and an increased understanding of soil contamination, food quality, and the scientific process.

Several participants asked to have their chicken eggs sampled to determine the concentrations of arsenic and heavy metals. They hypothesized that the deaths of some of their chickens were due to the arsenic and heavy metal concentrations observed in their potable water, soil, and vegetables. Further, they wanted to determine if there was a correlation between the exposure pathways and the concentrations found in the eggs. Another participant inquired whether cinder blocks in a raised garden bed contributed arsenic to their soil, and if samples from the local river or the soil from a local farm had been tested. Participants' questions were answered and the chicken eggs were analyzed. Results were reported back to the participants, who then shared the results with others. These inquiries signify the increase in capacity within the community and could also constitute a community-level outcome.

When comparing report-back methodologies by Brody et al., (2007) and those used for *Gardenroots*, one can observe many similarities in what participants want to know and how to make the information meaningful for action (see table 2). In summary, the UA scientists learned the importance of reporting individual results with an understanding of what people want and need to know to guide action, as witnessed in other studies (29). Additionally, it is important to present specific steps that the community can take to assert some level of control in their lives and methods in which they can implement to reduce their exposure to potential environmental hazards (5).

Programmatic outcomes

The *Gardenroots* project has contributed to the fields of environmental science, environmental health, and research translation. Currently, there is limited information regarding combined arsenic exposure from water, soil, and homegrown vegetables neighboring hazardous waste sites. This PPSR project has improved our understanding of: 1) the uptake of arsenic in common homegrown vegetables grown in soils near a mining site (28); and 2) the amount of arsenic introduced to an individual via the ingestion of homegrown vegetables, soils (incidental), and water, and potential risks posed by those exposure routes (23). This data has been published and demonstrates that community members can successfully participate in environmental science investigations. Lastly, *Gardenroots* participants reviewed this manuscript to ensure the integrity of the project and representation of the partnership.

Community-level outcomes – redefining the question and policy implications

Gardenroots increased social capital and community capacity by serving as a platform for participants to learn more about environmental contamination in general and the Iron King site, and was a catalyst to generate environmental communication efforts amongst the participants and the rest of the community. As a result, participants increased their community networking in resource-related issues and participated in other resource-related projects. Based on conversations with participants, there was interest in leveraging the results to pressure government officials to take action and be more stringent in their cleanup efforts. This is similar to other work in contaminated areas (27).

For example, the *Gardenroots* project revealed that the local public water system was serving water that exceeded the arsenic drinking water standard (0.010 mg/L). *Gardenroots* participants worked together to identify and notify additional households that were connected to the public water supply. They also reported their test results to USEPA and ADEQ, advocating that this issue needed to be addressed (UA also notified and sent the results to the USEPA). As a result, the municipal water suppler was issued seven Notices of Violation by the ADEQ, one for exceeding the arsenic drinking water standard. In the words of a *Gardenroots* participant: "The people in Humboldt served by Humboldt Water System are deeply indebted to Mrs. Ramirez-Andreotta's study which served to reveal a serious problem with the municipal water." Additionally, arsenic concentrations in water exceeded the drinking water standard for several participants who rely solely on their private wells for potable water. UA personnel worked closely with those households to provide information regarding water treatment technologies that could be implemented to reduce their arsenic concentrations. Now, the community is reporting that they are regularly testing their private wells, and are encouraging ADEQ to ensure that water entering their home is at or below the arsenic drinking water standard.

Furthermore, *Gardenroots* built trust between the UA scientists and the Dewey-Humboldt, Arizona community. This trust has set the groundwork for a long-term community-academic partnership. Due to the efforts discussed above, three additional research projects have been initiated to address pressing remediation and characterization challenges posed by the Iron King site. For example, the Metals Exposure Study in Homes was designed to determine the levels of metal exposure in children ages 1-11 years. Two former *Gardenroots* participants have been hired as UA employees to be part of the local field team. This is evidence that the *Gardenroots* community-academic partnership has enhanced social capital and community capacity and has even had a small economic impact in the community.

Discussion

Several limitations were observed throughout the project and these are also presented in table 1. First, setting and maintaining the expectations was a challenging. For example, *Gardenroots* could provide environmental monitoring and potential soil, water and vegetable exposure data, but could not provide specific data related to health outcomes. It was important to restate the goals and what type of data could truly be expected from the project. Second, due to the nature of the sample analyses and formal laboratory procedures, the participants did not get to prepare and analyze their own samples. In response, participants were invited to a laboratory tour called "The Science Behind *Gardenroots*" at the UA to learn the methodologies. Unfortunately, the attendance was low, and this was most likely due to the travel distance (~200 miles) and large time commitment. Lastly, even though *Gardenroots* informed the USEPA and ADEQ on all activities, it was challenging to maintain bidirectional communication between the *Gardenroots* project leader and all government agencies working at the site. At one point, EPA did not agree with the communication methodology, was uncomfortable with a few community member's responses and activism (Ramirez-Andreotta et al., forthcoming).

Reflecting on the process

Gardenroots satisfied the concepts of a co-created citizen project (co-created PPSR) based upon the level of participation throughout the scientific research process (Table 1), as compared to a contributory project (where participants solely collect samples) or a collaborative project (were participants may be involved in five or more additional steps) (12). In addition, *Gardenroots* was a CBPR project that, as originally outline by Israel et al., 1998, recognized the community as an unit of identity, facilitated collaborative, equitable involvement of all partners in most phases of the research, integrated knowledge and intervention for mutual benefit of all partners, promoted a co-learning and empowering process, and disseminated findings and knowledge gained to all partners. There are more components involved in CBPR, but not all projects require or are functionally set up to involve each and every component. It is important to be flexible and adapt to what is actually feasible, while successfully meeting and maintaining the expectations of the community-academic partnership.

In addition to describing risk, practitioners must also put the risk into perspective and in terms of consumption behavior. Converting the raw risk data into a personalized, more relatable format, specifically the quantity of vegetables they could consume at various target risks, and comparing this exposure route to water and soil ingestion was instrumental in translating the *Gardenroots* results. It is recommended that participants be given all of their personal data to review so that they can then decide for themselves which risk level is comfortable for them. This act can also facilitate inquiry and knowledge synthesis where participants compare and combine the results with their existing knowledge, furthering their inquiry-based learning.

Public participation methods have been used for a few exposure assessment and health studies, but not in conjunction with risk communication at a Superfund site. This case study demonstrates that risk communication efforts can be effective when the affected community is involved in the research project and in determining the content of the risk analysis. In addition, evaluating program outcomes at the individual, programmatic, and community levels is a useful and creative way to capture the successes of citizen science and community-academic partnerships.

In summary, the project design clearly justifies public participation in scientific research projects, hopefully may influence national policy regarding environmental science education practices for the general public, and definitely redefines who may generate environmental monitoring data in site assessments.

Acknowledgments

The authors would like to give a special thanks to all the *Gardenroots* participants for their participation and assistance in the project and for reviewing this manuscript. Additionally, the authors would like to thank the town of Dewey-Humboldt, Arizona, Jeff Franklin, Dewey-Humboldt Town Librarian, Jeff Schalau, UA Yavapai Cooperative Extension Director, Mike Kopplin, UA Superfund Research Program's Hazard Identification Core, and Dr. Atasi Ray-Maitra, UA Water Quality Laboratory. Lastly, thank you to Dr. Phil Brown for his comments on this manuscript.

This research was funded by the US EPA Office of Research and Development and NIEHS' Superfund Research Program (Grant P42 ES04940). The first author gratefully acknowledges financial support by the NASA Space Grant Program, UA TRIF Water Sustainability Program, and the Alfred P. Sloan Foundation that funds the National Action Council for Minorities in Engineering Scholarship program.

Supplemental Material

Supplemental Material Table 1. Demographics of *Gardenroots* participants (N=18)

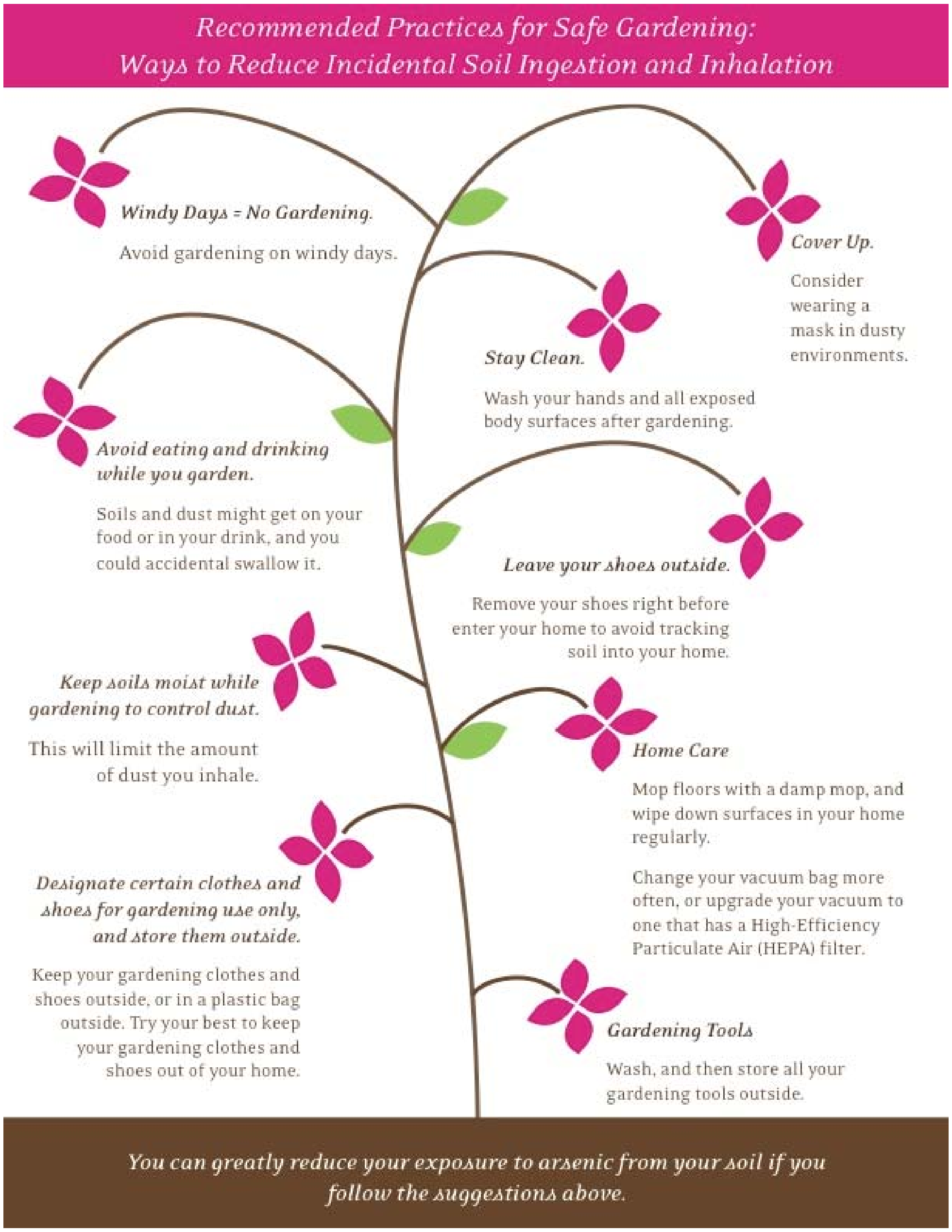
Demographics	Percentage
Gender	
Male	37
Female	63
Age (years)	
18 – 28	5.0
29 – 39	5.0
40 – 49	11
50 – 59	37
60 – 69	32
70 – 79	5.0
80+	0
Last academic Experience	
High School	22
Community College, Associates Degree	33
University/College, Bachelor's Degree	17
University/College, Masters/PhD	11
Trade/Technical School/Training Program	11
Years living in the area	
0 – 2 years	21
3 – 5 years	26
6 – 8 years	16
8+ years	37

Note: Percentages adding to less than 100% signifies missing data.

Location	**Target Risk 1/1,000,000**	**Target Risk 1/100,000**	**Target Risk 1/10,000**	**USDA Recommended Amount (cups/week)**
Onion				
Your Garden	3/4	7	70	4 cups/week total of "Other Vegetables"
Lettuce				
Your Garden	1/2	5	50	3 cups/week total of "Raw Leafy Dark Green Vegetables"
Tomato				
Your Garden	1-1/2	15	150	5 cups/week of "red and orange vegetables"

This is just an example; no actual community member results are shown.

Supplemental Figure 1. Amount you can eat from your garden based on a varying cancer target risk. An example of the risk communication and graphical layout selected to inform and properly answer the research question posed by the community: "How much can I eat from my garden?"



Supplemental Figure 2. An example of one of the three waterproof handouts that were made to disseminate the recommended behavioral modifications necessary to reduce arsenic exposure.

References

[1] Brown P, Mikkelsen EJ. No safe place. Toxic waste, leukemia, and community action. Berkeley, CA: University California Press, 1990.

[2] National Research Council. Alternatives for managing the nation's complex contaminated groundwater sites. Washington, DC: National Academy Press, 2012.

[3] Chess C, Purchell K. Public participation and the environment. Do we know what works? Environ Sci Technol 1999;30(16):2685-92.

[4] Cox R. Environmental communication and the public sphere. Thosand Oaks, CA: Sage, 2013.

[5] Galvez MP, Peters R, Graber N, Forman J. Effective risk communication in children's environmental health. Lessons learned from 9/11. Pediatr Clin North Am 2007;54:33-46.

[6] Senier L, Hudson B, Fort S, Hoover E, Tillson R, Brown P. The Brown Superfund Research Program. A multistakeholder partnership addresses real-world problems in contaminated communities. Environ Sci Technol 2008;42(13):4655-62.

[7] Silbertown J. A new dawn for citizen science. Trends Ecol Evol 2009;24(9):467-71.

[8] Miller-Rushing A, Primack R, Bonney R. The history of public participation in ecological research. Front Ecol Environ 2012;10(6)285-90.

[9] Thoits PA, Hewitt LN. Volunteer work and well-being. J Health Soc Behav 2001;42:115–31.

[10] Wilson J, Musick M. The effects of volunteering on the volunteer. Law Contemp Probl 1999;62(4):141–68.

[11] Flemming W. Volunteer watershed health monitoring by local stakeholders. New MexicoWatershed Watch. J Environ Educ 2003;35(1):27–32.

[12] Bonney R, Ballard H, Jordan R, McCallie E, Phillips T, Shirk J, Wilderman CC. Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. Washington, DC: Center Advancement Informal Science Education (CAISE), 2009.

[13] Israel BA, Schulz AJ, Parker EA, Becker AB. Review of community-based research. Assessing partnership approaches to improve public health. Annu Rev Public Health 1998;19:173–202.

[14] Brown P. Popular epidemiology and toxic waste contamination. Lay and professional ways of knowing. J Health Soc Behav 1992;33(3):267-81.

[15] Corburn J. Street science. Community knowledge and environmental health justice. CAmbridge, MA: MIT Press, 2005.

[16] Brossard D, Lewenstein B, Bonney R. Scientific knowledge and attitude change. The impact of a citizen science project. Int J Sci Educ 2005;27(9):1099–121.

[17] Evans C, Abrams E, Reitsma R, Roux K, Salmonsen L, Marra PP. The Neighborhood Nestwatch Program. Participant outcomes of a citizen science ecological research project. Conservation Biol 2005;19(3):589-94.

[18] Trumbull DJ, Bonney R, Bascom D, Cabral A. Thinking scientifically during participation in a citizen-science project. Sci Educ 2000;84:265–75.

[19] Falk JH, Storksdieck M, Dierking LD. Investigating public science interest and understanding. Evidence for the importance of free-choice learning. Public Underst Sci 2007;16:455-69.

[20] Ramirez-Andreotta MD, Brusseau ML, Artiola JF, Maier RM, Gandolfi AJ. Environmental research translation. Enhancing interactions with communities at contaminated sites, forthcoming.

[21] Gallagher DR. Advocates for environmental justice. The role of the champion in public participation. Local Environ 2009;14(10):905-16.

[22] Green L, Fullilove M, Evans D, Shepard P. "Hey, Mom, thanks!" Use of focus groups in the development of place-specific materials for a community environmental action campaign. Environ Health Perspect 2002;110(2):265–9.

[23] Ramirez-Andreotta MD, Brusseau ML, Beamer P, Maier RM. Home gardening near a mining site in an arsenic-endemic region of Arizona. Assessing arsenic exposure and risk via ingestion of home garden vegetables, soils and potable water. Sci Total Environ 2013;454-455:373–82.

[24] Jordan RC, Ballard HL, Phillips TB. Key issues and new approaches for evaluating citizen-science learning outcomes. Front Ecol Environ 2012;10(6):307-9.

[25] Brown P, Brody JG, Morello-Forsch R, Tovar J, Zota AR, Rudel RA. Measuring the success of community science. The Northern California Household Exposure Study. Environ Health Perspect 2012;120(3):326-31.

[26] Baron S, Sinclair R, Payne-Sturges D, Phelps J, Zenick H, Collman GW, et al. Partnerships for environmental and occupational justice. Contributions to research, capacity and public health. Am J Public Health 2009;99(Suppl 3):S517–25.

[27] Adams C, Brown P, Morello-Frosch R, Brody JG, Rudel R, Zota A, et al. Disentangling the exposure experience. The roles of community context and report-back of environmental exposure data. J Health Soc Behav 2011;52(2):180–96.

[28] Ramirez-Andreotta MD, Brusseau ML, Artiola JF, Maier RM. A greenhouse and field-based study to determine the accumulation of arsenic in common homegrown vegetables. Sci Total Environ 2013;433:299-306.

[29] Brody JG, Morello-Frosch R, Brown P, Rudel RA, Altman RG, Frye M, et al. Improving disclosure and consent: "is it safe?": new ethics for reporting personal exposures to environmental chemicals. Am J Public Health 2007;97(9):1547-54.