To cite this article:
Golumbic, Y. N., Baram-Tsabari, A., & Fishbain, B. (2019). User centered design of a citizen science air quality monitoring project. International Journal of Science Education, Part B. DOI: 10.1080/21548455.2019.1597314

User centered design of a citizen science air-quality monitoring project

Yaela N Golumbic[a,b], Barak Fishbain[b] and Ayelet Baram-Tsabari[a]

[a] *Faculty of Education in Science and Technology, Technion- Israel Institute of Technology;*
[b] *Faculty of Civil and Environmental Engineering, Technion- Israel Institute of Technology.*

Abstract

Technological developments, social networking and the emergence of sensory micro computation platforms have facilitated the recent growth of citizen science online communities. As a field of public participation in scientific research, citizen science provides lay audiences with platforms for data collection, submission and classification alongside access to large scientific databases and opportunities to engage in dialogue with experts. Although these platforms are intended for non-experts, they are often set up and designed by scientists, who may not fully appreciate the public's needs for such platforms. This sometimes results in platforms that are not compatible with users' needs and thus are underused and do not exploit the possibilities available. This article describes the use of Human Computer Interactions (HCI) design principles in a citizen science project for monitoring air-quality in the local environment. Using interviews, focus groups, questionnaires, and log data from the project website (n=138), in a three-phase iterative process that lasted 20 months, we identified public interests and suggestions for an online data presentation platform. The findings suggest participants were interested in real time, local, easy to understand information, which is practical, ready-to-use and presented in context of local laws and regulations. These insights were implemented in the design of a new platform, constructed as a simple three-layer information display with representations of air quality standards and practical recommendations. We examine the participants' use of the platform and discuss motivations and impediments to participation in the future design of citizen science projects for enhancing public engagement in science.

Keywords

User-centered-design, citizen science, public engagement with science, air quality

Introduction

Citizen Science is a general term describing the involvement of laypeople in scientific research. It refers to a range of projects with diverse scientific, educational and civic goals generally based on cooperation between scientists and non-scientists (Bonney et al., 2009; Silvertown, 2009). In the last ten years , citizen science has become a specific field of study with several citizen science associations whose members number in the thousands (Storksdieck et al., 2016). These associations are present in many scientific disciplines including biology, physics, computer science, and geology (Silvertown, 2009), and more recently, in social and political science (Crain, Cooper, & Dickinson, 2014).

Citizen science has not grown in a vacuum. Members of the public have been recording history, investigating scientific questions, and conducting observations of the world around them for generations (Silvertown, 2009). The recent rise of citizen science has been powered to a large extent by the emergence of sensory micro computation platforms and advanced communication technologies (Bonney et al., 2014). These new technologies can integrate sensory data with observations and real-time data displays, in addition to their social networking capabilities, image analysis and identification features (Dehnen-Schmutz, Foster, Owen, & Persello, 2016; Graham, Henderson, & Schloss, 2011). This progress has also enabled the development of citizen science projects that have no physical elements and are carried out solely online. Examples of these "virtual projects" (Wiggins & Crowston, 2011) can be found on the Zooniverse (www.zooniverse.org) platform. People can interact with projects by submitting data online, and by classifying and interpreting sounds, videos, or pictures, or by searching large databases (Bonney et al., 2014).

The design and development of online citizen science platforms is a challenging process (Senabre, Ferran-Ferrer, & Perell, 2018). Since every project has specific characteristics and constraints, there is no single tool or framework to guide these projects (Yadav & Darlington, 2016). The increasing amounts of data co-collected and analyzed by citizen scientists and the increased accessibility of data underscores the need for methodologies to handle visualization and readability. The field of Human Computer Interactions (HCI) deals with the design, evaluation and implementation of computing systems for human use (Sinha, Shahi, & Shankar, 2010), and can help support the development of rich, interactive citizen science communities and online platforms (Preece, 2016).

In successful online communities, members return repeatedly and contribute material and information that others value (Ren & Kraut, 2014). This is also true in the case of citizen science projects, where returning participants are responsible for the largest share of the contributions (Prestopnik, Crowston, & Wang, 2017; Sauermann & Franzoni, 2015). The failure of online communities is often attributed to their design, which is based on intuitive decision making and trial and error, rather than a systematic understanding of members' motivations and contributions (Ren & Kraut, 2014). To alleviate these concerns, participatory design elements can be harnessed to attract and engage users in online communities (Muller, 2003). This type of design considers end users as full participants in activities leading to software development and computer based products (Muller, 2003). Thus resulting in a product that responds more closely to users' needs and experiences, empower users, and is more likely to succeed (Wilkinson & De Angeli, 2014).

The goal guiding this study was to explore the ways in which HCI design principles contribute to the design of online citizen science projects. We describe how a User Centered Design (UCD) approach was harnessed for the development and evaluation of a citizen science project for monitoring air quality in the local environment. UCD is a design processes based on active involvement of users in improving the platform and conducting iterations of the design and evaluations (Mao, Vredenburg, Smith, & Carey, 2005). This approach allows end users to influence how the design takes shape, thus leading to a more effective and efficient product and contributing to its success (Abras, Maloney-Krichmar, & Preece, 2004). UCD was coined by Donald Norman in the 1980s, to underscore the importance of fully exploring users' needs, desires and intended use of a product (Norman & Draper, 1986). Since then it has further evolved to actively include product users in the design and evaluation process (Abras et al., 2004). While UCD is a time- consuming process and requires flexible design and constant modification of the product, it is thought to increase external (customer) satisfaction, enhance ease of use and make a significant impact on product development (Chammas, Quaresma, & Alvão, 2015; Mao et al., 2005). This paper explores the use of UCD in a citizen science context. We ask: How can UCD be harnessed to better understand the public's needs and interests in a citizen science online platform, and how can data be optimally presented in the platform to meet the needs of the community?

Conceptual Framework: Integrating Public Participation and Citizen Science

Public participation is still often evaluated on the "Ladder of Citizen Participation" (Arnstein, 1969) that classifies participation according to the extent to which publics become empowered. The scale ranges from "non-participation", through "tokenism" to "citizen power". At the highest level, participation equals control, where participants have full power over a program or institution, and are able to negotiate the circumstances for making changes (Arnstein, 1969). While this ladder has been critiqued for being simplistic and ignoring the challenges of involving the public in decision making (Brodie et al., 2009), it is also widely referred to and useful for understanding public participation in broader contexts. Similar to the "power-holders" and "have-nots" described by Arnstein (1969), citizen science includes experts - professional scientists, alongside laymen - the general public. Therefore, when discussing participation of the public in scientific research, these public participation typologies can be useful since they can help clarify the process of scientific research planning, and the complex public-scientist relationship (Haklay, 2013).

More recent participation typologies in citizen science identify three levels of public participation which are termed *Contributory, Collaborative* and C*o-Created* (Bonney et al. 2009). *Contributory* projects are those where the public contributes information to established research designed by scientists (e.g. The Monarch Larva Monitoring Project (MMLM)[1] where people collect butterfly observations, and submit the data primarily online). *Collaborative* projects involve the public in data collection, data analysis and interpretation (e.g. The Invasive Plant Atlas of New England (IPANE)[2] which creates a web-accessible database). C*o-created* projects engage the public in all phases of the research process including project design, data analysis and disseminating conclusions (e.g. Gardenroots[3] assesses contaminated soil in gardens and the risk of exposure). Co-created projects are of special interest in the context of this article since they are often initiated by citizens, who then collaborate with scientists in the research process. This guarantees the consideration of public interests and agenda in the research plan and execution. Such projects have been shown to be especially useful in addressing complex problems arising in local communities, particularly when addressing contamination or pollution (Ramirez-Andreotta et al., 2016). Although co-created projects are in fact "citizen power" projects, they constitute less than 5% of citizen science projects worldwide (Roy et al., 2012).

Today, most active citizen science projects are contributory projects (Roy et al., 2012) and the main research activities open to the public are observation recording, data entry, and species identification (Wiggins & Crowston, 2015). These forms of projects consider the goal of citizen science to be promoting scientific research. Scientists' reasons for participating in such projects are often influenced by their interest in advancing scientific research (Riesch & Potter, 2014), to obtain funding and to publish (Golumbic et al., 2017). Nevertheless citizens who take part in citizen science projects can benefit in many ways (Shirk et al., 2012) including hands-on exposure to scientific processes, the acquisition of new skills and knowledge, enjoyment, and community building (Brossard, Lewenstein, & Bonney, 2005; Dickinson et al., 2012; Golumbic, Baram-Tsabari, & Fishbain, 2016). However, providing benefits for participants is often a secondary advantage of citizen science and is not always considered a focus of the projects (Sagy et al., 2019).

The key factors in maintaining participation in citizen science lie precisely in retaining these benefits, and in making citizen science more inclusive and relevant for citizens (Baruch, May, & Yu, 2016). The synergy between citizens' and scientists' motivations (e.g. interest in the project and expanding knowledge vs. receiving scientific data) that fuel and preserve the collaboration between the two (Rotman et al., 2012). Balancing the data scientists need to collect and user satisfaction is the prime challenge facing platform designers (Sprinks, Wardlaw, Houghton, Bamford, & Morley, 2017). While the use and number of online citizen science platforms is growing, scant attention has

[1] https://monarchlab.org
[2] https://www.eddmaps.org/ipane/
[3] https://gardenroots.arizona.edu

been paid to methods for the design of these platforms (Sturm et al., 2018). Recent studies have indicated that platforms need to provide feedback and training to the participants, clearly disseminate the results, and provide a good user experience (Baruch et al., 2016; Wald, Longo, & Dobell, 2016). However, these calls have remained general and do not provide guidelines for implementation. The recently published National Academies of Sciences Engineering and Medicine (2018) report emphasizes the importance of dedicated design to amplify citizen science learning opportunities.

Citizen science can make science more inclusive and relevant for citizens by challenging the norms of scientific investigation, participation and knowledge production (Storksdieck et al., 2016). By considering all citizen science stakeholders and designing with them in mind, projects can be better directed toward meeting society's needs. These should be expressed not only in co-created initiatives, but in all citizen science projects.

Methods

Setting: Sensing the Air

This study was conducted as part of the citizen science initiative "Sensing the Air", a collaboration between scientists at the Technion Israel Institute of Technology and residents of a nearby neighborhood in the city of Haifa. It was initiated as one of the seven case studies of the European "CITI-SENSE" project for developing sensor-based citizen observatories (Kobernus et al., 2015). The aim of Sensing the Air is to facilitate air quality research in the city through the active involvement of volunteers and the collection and interpretation of meaningful air quality data (Figure 1).

Throughout the project, 30 air quality sensors were deployed in citizens' homes and public places that continuously monitored the air quality of the local environment. Sensors were relocated periodically, according to project progress. This created a local network distribution of sensors in houses, streets, parks, schools etc. Participation entailed the collection and analysis of air quality data, defining research questions, and developing ways to improve air quality in the neighborhood, and lower personal exposure to air pollution.

All data collected from the air quality sensors were made available online by a data presentation platform designed exclusively for this project, using a UCD process (see below). Participants had access to all the data collected by the air quality monitoring units. They could use the data for their personal benefit (e.g. reduce personal exposure to air pollution by avoiding polluted areas), analyze the data, discuss the results on social media, make suggestions for further research and use their new scientific knowledge for purposes of social involvement.

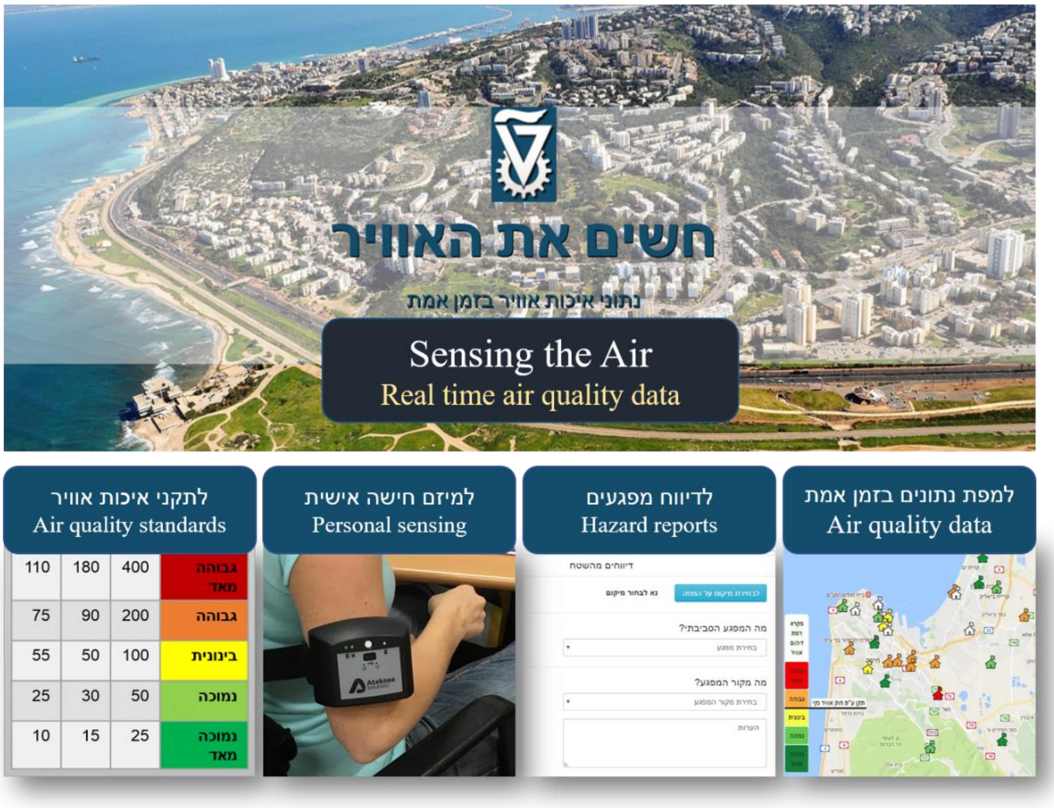


Figure 1. Sensing the Air web platform for facilitating air-quality research through active involvement of volunteers and interpretation of meaningful air-quality data.

According to the Ministry of Environmental Protection (MoEP), the Haifa bay industrial zone is one of the most sensitive areas in Israel in terms of air pollution. This is due to its large concentration of petrochemical industrial facilities and the Haifa seaport which are all in physical proximity to residential areas, in addition to topographical and climatic factors that affect the dispersion of pollutants (MoEP, 2015). The MoEP in Israel has invested considerable resources in reducing air pollution emissions in the Haifa bay over the past 10 years, resulting in a 70% emission decrease during this period (MoEP, 2014, 2015). The 2016 national program for reducing air pollution and environmental risks in the greater Haifa area is further expected to reduce industrial air pollution by an additional 50% by 2020 (Environmental and Health Fund and Ministry of Health, 2017).

Despite this documented reduction in air pollution, in April 2015, an internal Ministry of Health document linking air pollution in Haifa to increased incidence of cancer was leaked and published in the media. This brought Haifa's air pollution to the attention of the public and sparked vast public protest. This document was based on a 12 year cohort study indicating the increased incidence of cancer across all age groups in the sub-districts of Haifa compared to the rest of Israel (Rottenberg et al., 2013). However, an association between air pollution and cancer was not examined nor established in this study. The conflicting messages regarding air pollution sources, emissions and health implications make it difficult for citizens to form an informed opinion on air quality in Haifa and its impact on personal health. This setting provided powerful reasons for a public participation project in air quality research.

Research Approach: Applying a User Centered Design

The design of a user-friendly, practical platform for air quality data collection and presentation drew heavily on user feedback and experience. This process was facilitated by a UCD, an iterative practice that consists of revisiting the problem, re-analyzing it and synthesizing revised solutions (Swann, 2002). This was done using a combination of the Lazar (2001) and Preece (2000) life-cycle models for user centered development (Figure 2). The combined life-cycle model was composed of five stages of development: assessing the needs of the community, creating a conceptual design, implementing the design, testing usability and establishing the product. This model was repeated three times, providing three phases of evaluation and design.

- Phase 1: Towards a prototype: Initial design and evaluation
- Phase 2: Platform introduction: full version launch and user requirement survey
- Phase 3: Final touches: user assessment and platform refinement

The use of the life-cycle model ensures that users are included in the design, and that there is appropriate planning and testing throughout the process (Lazar, 2001). Each of the three phases contributed to better design and development of the presentation platform tool, and constituted an additional step towards the clarification and usability of the data presented. The data presentation tool was refined in parallel to its ongoing evaluation in each step of its development.

In conjunction with the development process, and to better reflect public reactions and comments, we identified main themes that emerged from each of the three phases. These themes consolidated the public's demands, and enabled their generalization to other potential situations.

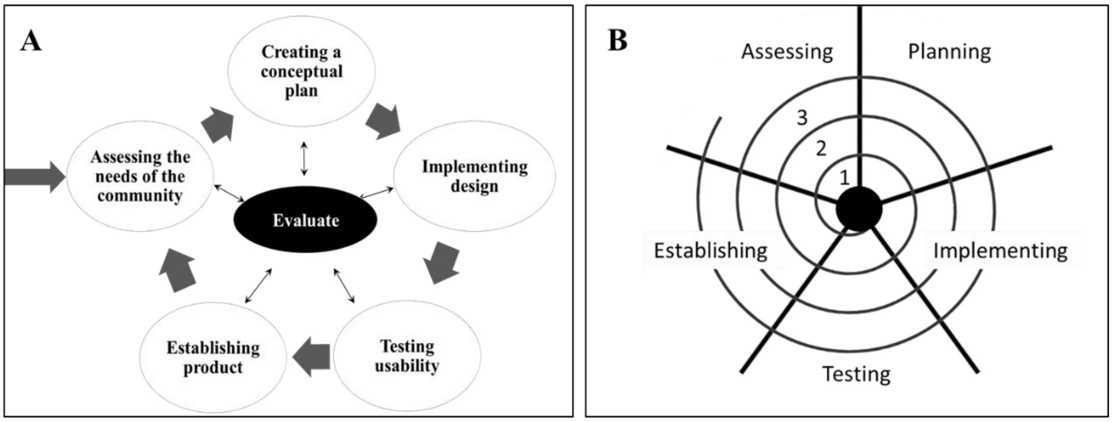


Figure 2. Life-cycle model used for user centered design in Sensing the Air. A. Five stages of development in UCD cycle. B. A spiral process of evaluation and design with three repeats of the life-cycle model.

Participants and Data Collection

A total of 131 participants took part in this study throughout the three research phases (Table 1). It was composed of residents of the neighborhood hosting sensors in their homes and other active participants in the project website. Participants were recruited by advertisements in air quality *Facebook* groups, email distributions by colleagues and friends, and responses from readers of the project website. They ranged in age from 20-70 with an equal representation of men and women. Most participants were highly educated, since only 14% did not have an academic degree. These demographics are consistent with other citizen science projects which tend to have educated, middle and upper socioeconomic class samples (Soleri et al., 2016).

Data collection applied a mixed methods approach, which aims to draw from the strengths of both qualitative and quantitative research paradigms (Johnson & Onwuegbuzie, 2004). The data collection tools included semi-structured interviews, focus groups, two questionnaires, and website log data. Each of the three design phases used different data collection methods (Table 1). The data collection period spanned 20 months (April 2015- November 2016) in which the design and building of the platform took place. All the data were collected and analyzed in Hebrew and representative segments were translated into English.

Table 1. Data collection methods used in the three design phases, indicating the number of participants in each stage. Some overlaps may have occurred across design phases and/or data collection tools.

	Interviews	Focus groups	Open ended questionnaire	Close ended questionnaire	Log data of platform usage
Phase I	N= 12	1 group, N= 5	-	-	-
Phase II	-	-	N=18	N= 80	-
Phase III	N= 9	1 group, N= 7	-	-	N= 1114

Semi Structured Interviews

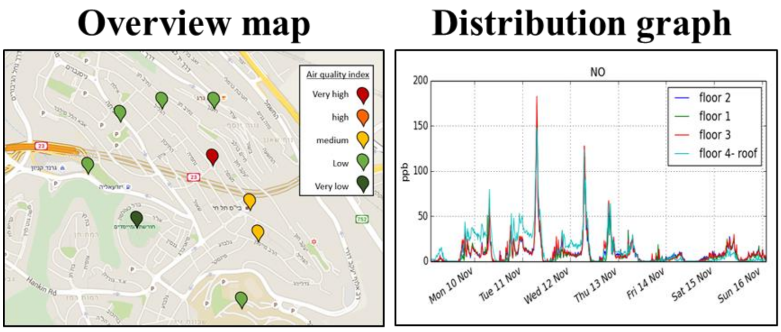
Interviews were conducted during phases I and III and examined participants' views concerning air quality data. Semi structured interviews were selected since they ask all interviewees the same open-ended questions, but still maintain flexibility and enable variations and personalization of the interview protocol (Given, 2008). The interviewees were generally more active participants who hosted air-sensors in their homes or volunteered to assist in other time-consuming activities (such as help with sensor distribution or development) (Table 2). The interviews were conducted individually or with couples living in the same household, lasted about one hour, and took place mainly in the participants' homes or in the interviewer's office.

Table 2. Demographics of interviewees.

Pseudonym	Gender	Age	Education	Profession	Interviewed in phase
Lynn	Female	30-40	Professional certification	Secretary	Phase I
Martin	Male	30-40	Professional certification	N.D.	Phase I
Allan	Male	40-50	Academic degree	Engineer	Phase I+II
Judy	Female	60-75	Academic degree	teacher	Phase I+II
Burt	Male	20-30	N.D.	N.D.	Phase I
Sharona	Female	30-40	High school education	Journalist	Phase I
Michael	Male	40-50	Professional certification	Technician	Phase I
Jennifer	Female	30-40	Academic degree	Environmental education	Phase I
Adelle	Female	60-75	Academic degree	Education	Phase I
Rose	Female	20-30	Academic degree	Accountant	Phase I
Mark	Male	20-30	Professional certification	Computer software	Phase I+II
Jay	Male	30-40	Associate degree (Practical Engineer)	Test Engineer	Phase I+II
Harry	Male	30+	Academic degree	Policy	Phase II
Debbie	Female	70+	N.D.	N.D.	Phase II
Anne	Female	30+	Academic degree	Public health	Phase II
Bob	Male	30+	Academic degree	Engineer	Phase II
Susan	Female	40-50	Academic degree	Design	Phase II

N.D. = no data

During the interviews the participants were presented with air quality information according to the platform design at the time. In phase I, initial air quality data were displayed in three ways (see Fig. 3): 1) An overview map of the neighborhood with sensors marked in color according to the air quality measurements, on a 1-5 qualitative scale. 2) Comparative pollutant distribution graphs, with ppb (parts per billion) values. 3) Raw measurement data, presented in the form of a table. Participants were asked to explain what they understood from each type of presentation and which one they preferred. In phase III, participants were shown the most recent versions of the platform design, and asked what they understood from the data and if the presentations were clear, relevant and useful for them. The participants were encouraged to raise questions and suggestions for improvement.



Raw data

Time	O_3 [ppb]	NO_2 [ppb]
14:15 10/01/2015	57	20
14:30 10/01/2015	59	19
14:45 10/01/2015	60	19
15:00 10/01/2015	61	20
15:15 10/01/2015	60	16
15:30 10/01/2015	57	18
15:45 10/01/2015	59	22
16:00 10/01/2015	60	21
16:15 10/01/2015	59	17
16:30 10/01/2015	57	17
16:45 10/01/2015	55	21

Figure 3. Initial air-quality data presentation levels 1) An overview map with qualitative color-coded air-quality indications. 2) Comparative pollutant distributions graphs 3) Raw measurement data.

All the interviews were recorded, transcribed, and qualitatively analyzed using thematic analysis to group clusters of recurring issues (Braun & Clarke, 2006; Guest et al., 2011). These clusters generated the global themes that provided insights into participants' perspectives. This type of analysis exposes structures and underlying patterns in the text (Attride-Stirling, 2001). It yielded a systematic framework for analyzing the interview data and enabled the identification of implicit and explicit ideas within the text (Thomas, 2006).

Focus groups

Two focus groups were organized throughout the study, during the initiation of phase I and in phase III. Focus groups encourage self-disclosure, and work particularly well to explore perceptions, feelings, and thoughts about ideas, products and services (Krueger & Casey, 2014). The participants of the focus groups were prospect participants, interested in engaging in Sensing the Air activities. Similar to the interview process, the focus group participants were presented with the latest version of the platform design. After reviewing the design, a discussion was held about the clarity and usefulness of the data presentation platform. The focus group lasted about two hours, discussions were recorded, and transcribed. In addition, some of the members of the second focus group wrote down their reflections. Focus group discussions were qualitatively analyzed for emerging themes as described in the interview section.

Questionnaires

Two questionnaires were distributed during the evaluation of Phase II. The first was an open-ended questionnaire to identify the topics and types of information that interested the participants in the context of air quality. The questionnaire was distributed by email to participants of Sensing the Air and to people who attended a project event around the time of the questionnaire distribution. Participants were asked: "if you were with air quality experts and stakeholders what questions would you ask them?" This was done independently of the interview and focus group process and participants were not presented with the platform design at this stage, to prevent leading them to the type of information the site was already presenting. This resulted in 43 questions and comments from 18 participants. The questions were classified by general topic (i.e. pollution source, health risks, requests for information), and further clustered into main themes using second level coding which serves to move the analysis from specific details to general concepts, rules or relationships (Bazeley, 2013) (see results, Table 4). Intercoder reliability was examined and found to be above 90% agreement.

The second questionnaire was closed-ended, and was distributed to both participants and potential users of the platform using email listings of interested parties and *Facebook* groups. The questionnaire was constructed by the CITI-SENSE consortium and examined users' preferences for type of data presentation with different features on the platform (CITI-SENSE, 2016). For example, participants were asked: "If you could have an application which informs you about air quality, how important would it be to have the following features?" followed by a list of eleven predefined features. Respondents were asked to rate each feature on a 1-5 scale (Essential, High priority, Medium priority, Low priority, Not a priority).

Log data

The detailed actions of platform users were recorded and stored in log files for the duration of the study. These files included the time and date of each site visit, user logins, and activity on the site (such as viewing information, creating graphs and reporting hazards). During phase III of the assessment, these files were accessed to determine level and types of engagement. The log data were analyzed according to the user name of registered participants, and the IP number of non-registered participants. Identifiable bots were excluded from the log data prior to analysis. In total, there were 16,790 lines of data, 5,870 of which were identified as bots (a standard accepted number), with the remaining lines representing 1114 unique visitors to the platform. For each visitor, the number and duration of the visits were determined in addition to the registration and login to the platform and types of activities during the visit.

Ethical Considerations

IRB approval was obtained from the authors’ institutional committee (approval: Nov. 2014). Pseudonyms are used to preserve anonymity and privacy here. Log data were kept confidential and only the first author had access to them.

Results

A vision of a user-friendly, practical platform for air-quality data collection and presentation was the basis of designing the prototype described here. The results for the three development phases, the main themes in each phase and their implementation are detailed in Table 3.

Table 3. Summary of the three development phases, the main themes in each phase and the implementation in the design.

	Assessing the needs of the community	Conceptual plan	Implementing design
Phase I	Participants' requirements for data presentation are diverse, the platform must support this diversity	Multiple layers of information could help meet diverse needs	Three-layer information display was constructed including a general map, a specified pollutant display per location and graphs displaying pollutant concentrations over time
	Participants are interested in viewing processed information rather than raw data	Normalize the data to a standard qualitative scale	Information display was normalized in all three layers to a 1-5 qualitative scale of air quality (very high, high, medium, low, very low)
	Data should be in context and relate to the local air quality law	Addition of local air quality standards	Local air quality standards were added alongside the qualitative scale
	Trustworthy information from a reliable source	Specify the funding sources for the research and be transparent regarding the project's aims	A description of the study as a European Union funded project with a public participation goal
Phase II	Factual information about air quality, monitoring systems and operational data on the project.	Addition of air quality content and sensor distribution information	A monthly blog describing air-quality research was added, in addition to explanations on each of the pollutants measured. Pictures and short descriptions of each sensor's location were added.
	Interest in understanding air pollution conditions and health implications	Addition of average air quality levels, actions and recommendations	A summarized air-quality conditions and a short health recommendation was added, such as "low air pollution – usual outdoor activities"
Phase III	Simple information that is not time consuming to access	These needs were identified as impediments to participation in the final stage of development. They will further be addressed in future stages.	
	Data should support activism, not only research interests		
	Easy or no registration		

Phase I. Towards a Prototype: Initial Design and Evaluation

Assessing the needs of the community involved determining the types of information participants were interested in viewing, and the accessibility of the scientific data design. To understand the needs of the community, we conducted interviews with active participants (who hosted air-sensors in their homes or volunteered to assist in time-consuming activities), and a focus group with people interested in joining Sensing the Air activities. We asked participants what kind of information they would expect to see on such a platform.

Lynn, who installed an air quality unit in her home, replied: "*The level of pollution. What does the unit we installed actually show us*" Similarly, Michael who also installed an air quality unit in his home, asked: "*Would I be able to use the platform to see if the air quality on my street is good or bad now? Or will I only see raw data?"*. Allan said he was interested in seeing: "*Maps of... a colored map showing [pollution in] different areas*." These replies are indicative of the participants' interest in obtaining local air quality information. Whether in their homes or in the whole neighborhood, the participants expected the information to tell them what the air quality was like in a simple way they could understand.

To assess the scientific design of the prototype, we presented the participants with three levels of air quality data (as described in the Methods): a map, a graph and a table (Figure 3). Lynn's interpretation of the map was: *"There are a few sensors scattered here, we can say these streets have low air pollution. The red for example here, if I understand correctly, is high air pollution"*. Lynn explained the graph as follows: *"I understand that as the graph lines go up, there is more pollution*". When presented with the raw data she exclaimed: *"My head hurts just from looking at this"*. Similarly, Judy said: *"Raw data won't tell me much. I prefer looking at processed data"*. Lynn concluded: *"We, as people who want to participate, we want something simple. We [want to] look at it, and understand right away what it is we are seeing."*

Lynn's reaction represented the position of the majority of interviewees indicating participants understood and preferred the general map, and did not understand or think it was helpful to see the raw data. The distribution graph was clear to about half of the participants.

Additional insights included the need to contextualize the information. Martin looked at the map and said: *"Now I see this is yellow, that means medium. Medium air pollution. Now, what is medium air pollution?"* Similarly, participants in one of the focus groups said: *"Let us know what medium or good is, in the context of the accepted levels in the country"*. This shows their need to see the data in relation to local standards and regulations.

Allan had a comment regarding the time scales of the data: "*Real time information is not so interesting. It is more important [...] to see larger segments and longer time periods"*. He suggested: "*Longer periods of time can be averaged from the information in the platform, and then say press a button to choose a whole month's information*".

Burt commented: *"It might be worthwhile to put a sensor at the major intersection of the neighborhood. There is a lot of traffic there*". This suggestion, like many others, demonstrates the participants' involvement in the study and interest in the research topic. Clearly, the geographic proximity of the study to the participants' homes impacted their level of interest and participation.

Many participants related to the management and funding of the project. Sharona asked: *"Who is actually behind this project? Who is the funding body? […] there isn't some kind of [the name of one of the owners of a large industrial plant in the area] who on the one hand gives and on the other hand… [is the one polluting]"*. This statement highlights a general concern regarding air pollution in the area, and distrust in the agencies that may be funded or have a conflict of interests with polluting industries. Judy stated: *"If there were external bodies providing [air quality] information, that could be trusted, then we could do something with the information. Currently the situation is problematic"*. Knowing that the funding for Sensing the Air came from a European Union research institute was reassuring to the participants and framed it as a trustworthy project.

This input was used to develop a conceptual plan for the design of the platform and served as a basis for its implementation (see Table 3). We constructed a three-layer information display, including a general map, a specified division of pollutants at each location and graphs displaying the pollutant concentration over time (see Figure 4). This information display responded to the need for multiple layer information that presented local information in both real time and over time. We added local air quality standards to the qualitative scale and using the same scale, presented normalized data in all three layers. This addition responded to the demand for processed data and for contextualizing the information.

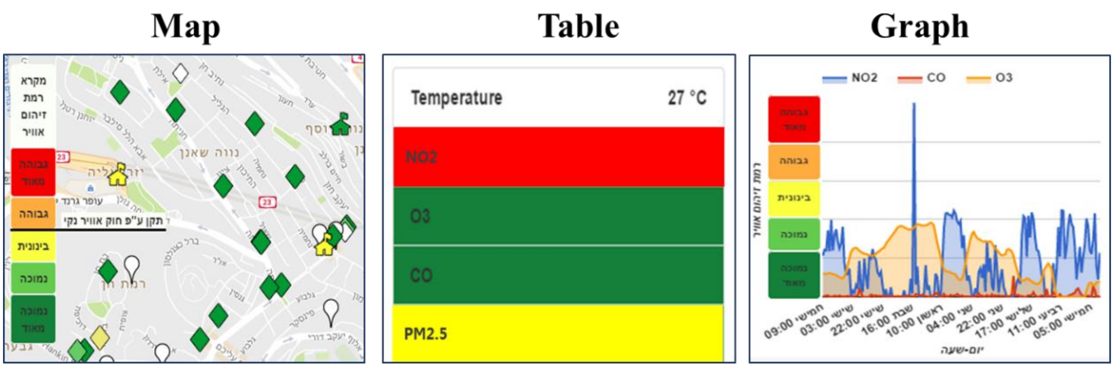


Figure 4. Three-layer information display constructed according to phase I of the design and evaluation process. The data presentation included a map presenting air-quality levels in many locations, a table displaying specific pollutants levels per location and a graph displaying pollutant concentration over time. Air-pollution levels are color-coded from red to green, indicating very high to very low pollution.

Phase II. Platform Introduction: Full Version Launch and User Requirements Survey

After the launch of the online data presentation platform (at the end of phase I), we again assessed the needs of the community. Phase II focused on platform comments from larger numbers of participants. Two online surveys were distributed via email to project participants. Eighteen participants raised 43 questions and/or comments on the air quality in Haifa ranging from requests for additional information about pollutants, the local monitoring system, to personal exposure and health implications. Four main themes were identified: 1) the need for additional factual information regarding air quality, the monitoring system, pollution sources, and operational data on the project. 2) the bottom line about pollution (is the air polluted?) and its health implications. 3) ways to take action by reducing personal risks and understanding the steps taken by the officials, 4) responsibility of official authorities and concerns (Table 4).

Table 4. Examples of questions raised by participants regarding the air quality in Haifa

Theme	**General topic**	**Number of questions**	**Examples**
Operational and Factual information	Local monitoring system	4	How many monitoring stations are there in Haifa?
	Project monitoring system	8	What pollutants does this project monitor?
	Pollution source and levels	5	Can the measuring tools attribute pollution to an emission source?
Bottom line and health implications	Concern about pollution	3	Is the air really polluted?
	Health risks	4	Is it dangerous for babies to live on the side of the mountain facing the industrial zone?
Actions	Reducing risks	5	What can the average citizen do to reduce air pollution or personal exposure?
Responsibility and trust	Official responsibility	8	Who enforces the law that no polluting substances should be emitted into the air?
	Distrust	7	Where can we get objective data?

The second survey asked participants about their preferences on a number of features on the data presentation platform. Of the 80 participants who returned the questionnaire (Figure 5) 80% responded it was essential or high priority to receive real time air quality data. Close to 70% indicated it was essential or high priority to present air quality in their immediate proximity and use an air quality index indicating whether the air quality was good or poor. Participants were less interested in the ability to report what they thought about air quality, with almost 50% responding this was low priority or not a priority at all.

These results largely confirmed the conclusions obtained in phase I of the study, and highlighted participants' desire to obtain real time, local, contextualized and processed data.

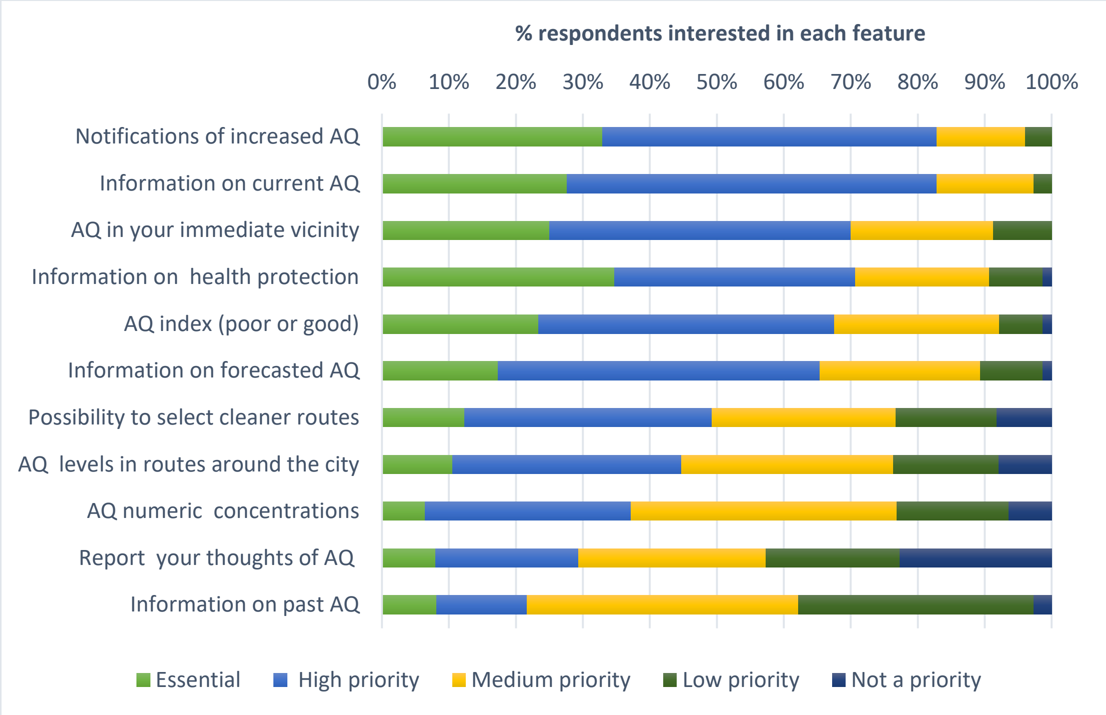


Figure 5. Participants' preferences for embedding features in the data presentation platform, based on the question: "If you could have an application which informs you about air-quality, how important would it be to have the following features?" n = 80.

Based on the findings from the two surveys, we went back to the design process, and added a number of features to the platform (Figure 6). Factual information such as explanations on each of the pollutants measured in the project, pictures and short descriptions of each sensor's location and micro-environment, and a monthly blog describing air quality research both locally and worldwide were added. We provided a summary of air quality status and a short health recommendation, such as "low air pollution – usual outdoor activities" or "medium air pollution – reduce or reschedule outdoor exercise". These changes were implemented over a four-month period as soon as they were ready to be released on the platform.

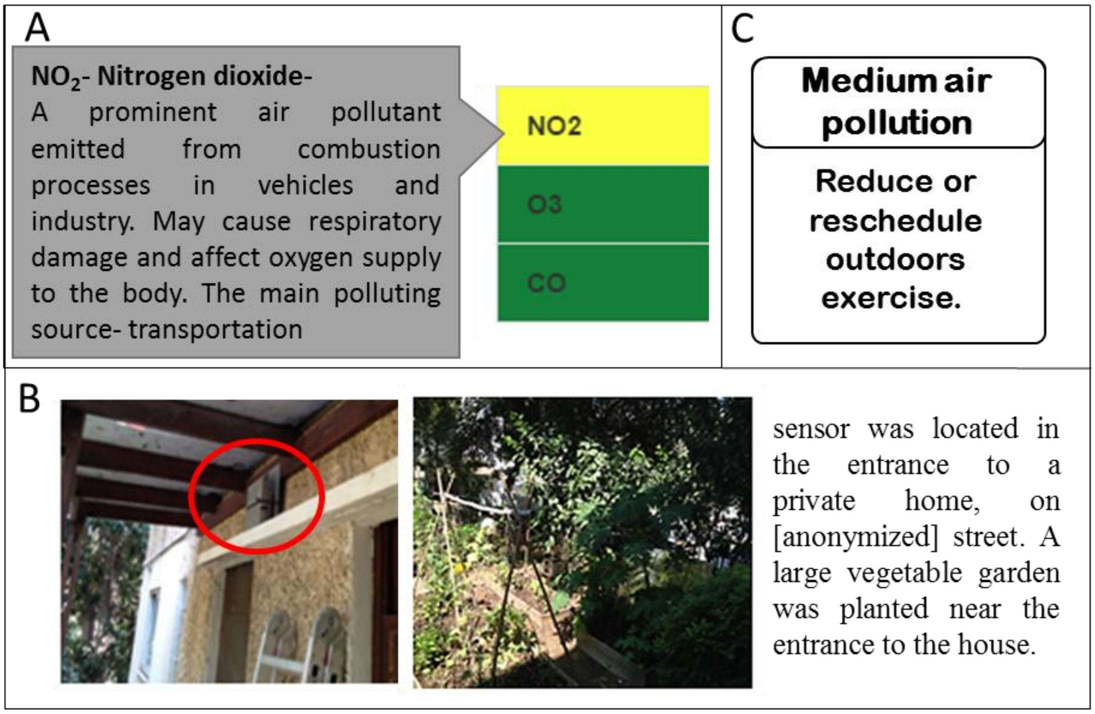


Figure 6. Additions made to the project platform during phase II. A- explanations on pollutants measured. B- pictures and short descriptions of sensor location and micro-environment. C- air-quality status and health recommendation. All texts are translated from Hebrew.

Phase III. Final Touches: User Assessment and Platform Refinement

This stage explored the actual use and number of visits to the platform after the ongoing release of new features on the platform. Platform log data were accessed and mined to account for individual visitors. This enabled us to identify the numbers of visits and activities by each visitor, and determine their levels of engagement. As levels of engagement increased, the numbers of users engaged in the activity decreased (Figure 7). Out of 1,114 unique visitors, only 148 registered and only 95 logged in at least once using the registration information they provided (the rest used the platform without registration or logging in). This limited their activity on the platform, since unregistered users could only view partial information. Forty users were recurrent and visited the site more than three times during the six months of log data sample.

To further understand the advantages and disadvantages of the platform, three participants from each engagement level (registered, logged in and recurrent) were interviewed (interviewing non-registered users was not possible since we did not have their contact information).

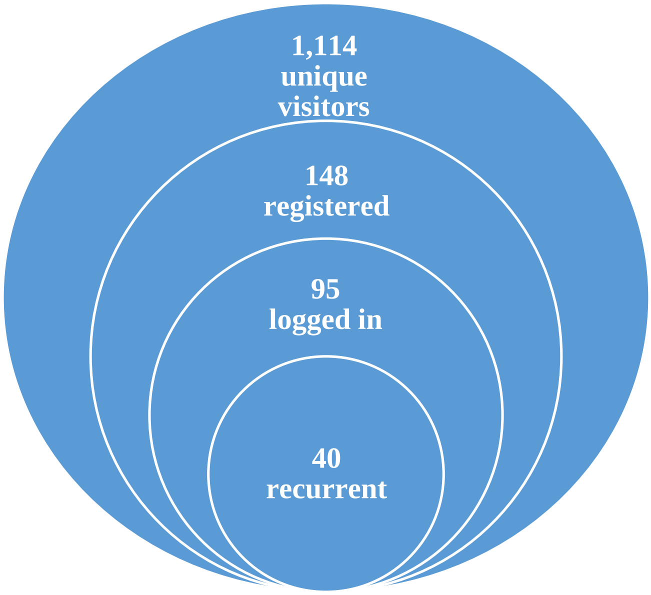


Figure 7. Number of platform users, as a function of levels of engagement. As levels of engagement increase, numbers of users decrease.

All the interviewees were highly motivated and thought the project was highly important and useful. Judy, a recurrent member (who was also interviewed in stage I), said: "*I am really fascinated by what you do, making data accessible to people who are not experts in the field, help them touch… connect what they feel, what they smell, what they see, with the scientific data*". This stance was also true for some of the non-active participants in the platform. Harry, a registered participant, who did not log into the platform after initial registration, said: "*The way I see it, this is very, very important […]. Anyone can take the information, and use it, do something with it*".

While not all participants were recurrent members, many of the interviewees stated the platform design was clear and useful. Anne, a logged-in participant said after her first visit to the platform: "*Overall from what I've seen so far, the platform is built really well*". When asked which parts of the platform she looked at, Anne replied: "*Everything. I entered all the links, it really interested me*".

Mark, a recurrent member said that the advantage of the platform was that it provides important information. He joined the project because of his concern for his children's wellbeing, and said "*I feel this is my responsibility as a parent*". Mark and his wife were looking to buy a house in the area, they wanted to make sure the air pollution was not a concern and thought the platform could help them, and that "*it is really user friendly*". Similarly, Debbie, a registered member said: "*It is very interesting to see the difference [in air quality] between different streets*". Debbie further volunteered to host a sensor in her house, perform air quality monitoring in different locations and recruit more volunteers for the project. However, in practice, Debbie never got around to doing any of these activities due to time constraints. She explained that she preferred spending her free time on activism and not on research.

Allan, a logged-in participant, also thought time was the main obstacle to being a more active member. He said: "*In the beginning I might visit the platform every two weeks, after that, it is hard for me to say*". This was despite the importance of the project in his view and its practical implications: "*I hope the outcomes of this project will get people more involved and put pressure... so there will be less air pollution in the neighborhood and in the playgrounds*".

On the other hand, Bob, a registered member, explained he was not an active member since his interests went beyond the scope of this project: " *I really want to see a heat-map, of what areas are not healthy. […] I am interested in knowing if I am poisoning my kids by breathing the air here. That's what interests me […]. My son is 5.5, he has been breathing this air for 5.5 years. Should I run away from Haifa? That's what interests me".*

The principles that helped shape the conceptual design were taken into account to improve the Sensing the Air platform and provide participants with the platform that best met their needs. This was echoed in the words of one of the focus group participants, after we implemented many of the changes: "*The platform is clear and provides the information to understand the topic… It was great to see the amount of data obtained when clicking on the sensor icon, and especially the health recommendations… The data are clear and available to all and that is a big advantage*".

Overall, the findings suggest there is no "right way" to design a platform, since different users have different interests in mind, spend their time in different ways and assign their priorities differently. Rather, designing a flexible interactive platform with various opportunities and levels of information can support diverse participation patterns, which is an important property of citizen science. Designing a multiple level presentation platform aimed at different levels of understanding can also increase the usability of the data.

Discussion

This study described the development of a data presentation platform for an air quality citizen science project using a user- centered design approach. Our aim was to utilize HCI design principles to better understand the public's needs and interests, determine ways to effectively respond to them and facilitate the design of a user-friendly platform that would meet the needs of the community. This process was iterative and accompanied by research practices to generalize our findings. The consolidation of the design and research goals was facilitated by a joint motivation to create a better reality (Austerlitz, 2006). In our case this reality was one in which scientific information is available and accessible to the general public in ways they can understand and use. A UCD was applied to understand the requirements of a citizen science data presentation platform, based on active involvement of users.

The contribution of this paper is twofold. First, we propose a novel approach to the design and evaluation of citizen science platforms which corresponds to users' needs and experiences. Second, we reflect on the development process of Sensing the Air, by highlighting the main points arising from the process, charting new insights into public participation and providing suggestions for future citizen science design.

The three-phase process of evaluation and design used to build Sensing the Air platform yielded many insights into public preferences and participation which could not have been identified otherwise (Table 3). The UCD process indicated, for example, that participants were interested in real time, local, and easy to understand air quality information. They wanted the data to be presented in the context of local laws and other cities in the country. Participants were interested in practical information, not only numbers and graphs but rather the bottom line and the implications of the data, including steps that could be taken.

The themes that arose during the conceptual design stage (such as presenting processed contextualized information, and providing bottom line and health implications) are consistent with research in the HCI field (Ren & Kraut, 2014). These studies suggest that simplifying information and creating easy-to-use web-based interfaces are an effective way of enabling wider public participation (May & Ross, 2018). HCI research further suggests that online platforms should strip away as much raw data as possible and present a simple concept to the end user (May & Ross, 2018). This is of special importance, since participants' cognitive resources are limited and an overload of unfiltered less relevant information could impede retention (Wald et al., 2016). This does not mean that raw data should not be available at all, but rather it should be one of many forms of data presentation.

Our findings are also in line with mainstream science communication practices which suggest that scientific topics are best communicated through visual representations (Lipkus & Hollands, 1999) that convey simple messages (Myers, Maibach, Peters, & Leiserowitz, 2015). They are also aligned with the standards suggested by Fischhoff (2013) that communication messages should contain information the recipients need, in places they can access, and in a form they can comprehend.

By turning to participants for input and feedback on project design, management and goals, changes could be made to adjust the project to everyone's needs. As demonstrated here, UCD helped identify and apply these needs. This process can turn "regular" contributory citizen science projects, as defined by Bonney et al., (2009) into inclusive ones, and the top-to-bottom approach into a two-way communication model. In so doing, an approach of this type can contribute to democratizing science, by creating a dialogue between citizens and scientists and by better addressing complex topics such as the development and application of science and technology in society (Cooper & Lewenstein, 2016).

A UCD for citizen science initiatives introduces upstream engagement in the design and planning of citizen science projects, and not only in participation. This process creates a more inclusive and attentive way to increase the attractiveness of online citizen science interfaces. In light of recent calls to create more inclusive citizen science projects that reflect the diversity of these communities and their concerns (Aristeidou, Scanlon, & Sharples, 2017; Soleri et al., 2016), our findings suggest there is no "one public" and that different people have different interests in mind. In order to serve these diverse audiences, it is important to be flexible in the options and levels of participation provided within the project, making many – not only the affluent and educated - comfortable in terms of their level of participation.

Nevertheless, using UCD does not guarantee active use of the platform. As demonstrated, although air quality in Haifa interested the people involved, it was not enough to prompt the active and persistent participation of all users. Less than 5% of the people visiting the online platform returned recurrently to interact with the platform. This percentage is similar to findings from other online citizen science platforms. For example, in the Zooniverse platform, only 4-7% of participants contributed data on multiple days or over a long periods of time (Sauermann & Franzoni, 2015). However, when looking at recurring members of Sensing the Air relative to the number of registered participants (expressing interest in the project) interaction activity increases to 12%, indicating the relevance of the platform. Participants noted that the final product was clear and useful and met the needs of the community. Similar findings were found in the citizen inquiry community Weather-it, where 13% of the registered members remained active for long periods of time (Aristeidou et al., 2017). Together, these results suggest that citizen guided initiatives can increase the relevance and support the retention of participants.

Participants who were not active in Sensing the Air platform stated the reasons were mainly time related, given their many other obligations and responsibilities. These results are consistent with many recent citizen science project evaluations (e.g. Eveleigh et al., 2014; Jennett et al., 2016; Rotman et al., 2012) and may stem from the nature of citizen science as a serious leisure activity, and its discretionary time commitment (Stebbins, 2007). Registration on the platform was also found to be a barrier since it limited the information participants were exposed to and their activity in the project. An additional barrier was the platform's emphasis on research rather than activism, since some participants did not identify scientific knowledge as relevant and important to their activist interests. Creating more personalized environments for participants could further increase levels of participation and engagement and introduce personal value for participants (Haywood, 2016; Sullivan et al., 2014).

Although the evaluation and design process described here involved only one project with a specific scientific topic, we believe the principles can be generalized to other data presentations and citizen science projects as well. Clearly, different projects may encounter additional themes that were not considered here, while some of the themes raised here may not apply due to the specificity of our study. Another limitation of this study is its local nature. Although some effort was made to include diverse audiences, this was limited to the geographical region of the project and hence may not accurately represent the whole population. Future research should expand this study to larger online communities and examine the feasibility of applying similar design process as described here.

Conclusion

This paper describes the design of one aspect of the Sensing the Air project: the data presentation platform. We aimed to explore the advantages and disadvantages of applying UCD in citizen science and implementing this approach for future designs. A similar approach could be used for designing the data collection, data analysis and communication aspects of the project. We found that applying UCD contributed to the design and development of the Sensing the Air platform, supported the public's needs and created a practical and useful user interface. It was extremely effective in providing insights into participants' needs and requirements from the platform.

This study highlighted the importance of listening to users' voices, accepting public feedback and embracing dynamic change when designing for public participation with science. These finding are consistent with the design principles of online communities that consider the understanding of local conditions and cultures to be a baseline requirement for successful design (Preece, 2016). Our finding are also concordant with studies in science communication that have examined effective ways to communicate scientific topics by supplying information people need, in an accessible place and an understandable fashion (Fischhoff, 2013).

Since the themes found in this study confirm those reported in other online projects, we believe they can be more broadly generalized, and used as suggestions for future citizen science designs. We therefor propose: 1. Provide diverse engagement opportunities and levels of information display. 2. Present normalized information that is processed and simplified 3. Standardize the information to the local context. 4. Be transparent in terms of the project's aims and funding sources. 5. Provide additional learning information 6. Be practical, connect the project aims and outcomes to the participants' lives. 7. Enable participation with quick and simple actions.

Further work should examine efficient ways to apply UCD to all aspects of citizen science projects to achieve optimal outcomes. Ultimately, implementing this process within future citizen science projects could significantly impact the practice of citizen science and help create more inclusive and relevant public participation in science through citizen science projects.

Acknowledgments

This research was supported by CITI-SENSE under grant agreement no. 308524 of the EU FP7-ENV-2012 and by the I-CORE Program of the Planning and Budgeting Committee and the Israel Science Foundation (1716/12).

Declarations of interest

None

References

Abras, C., Maloney-Krichmar, D., & Preece, J. (2004). User-Centered Design. In *Bainbridge, W. Encyclopedia of Human-Computer Interaction* (pp. 445–456). Thousand Oaks: Sage Publications.

Aristeidou, M., Scanlon, E., & Sharples, M. (2017). Profiles of engagement in online communities of citizen science participation. *Computers in Human Behavior*, *74*, 246–256. https://doi.org/10.1016/j.chb.2017.04.044

Arnstein, S. R. (1969). A ladder of citizen participation. *Journal of the America Institute of Planners*, *35*(4), 216–224.

Attride-Stirling, J. (2001). Thematic networks: an analytic tool for qualitative research. *Qualitative Research*, *1*(3), 385–405. https://doi.org/10.1177/146879410100100307

Baruch, A., May, A., & Yu, D. (2016). The motivations, enablers and barriers for voluntary participation in an online crowdsourcing platform. *Computers in Human Behavior*, *64*, 923–931. https://doi.org/10.1016/j.chb.2016.07.039

Bazeley, P. (2013). *Qualitative data analysis: Practical strategies*. (S. Jai, Ed.). London: Sage Publications.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., & Wilderman, C. C. (2009). Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. *A CAISE Inquiry Group Report*, (July), 1–58.

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., & Parrish, J. K. (2014). Citizen science: Next steps for citizen science. *Science*, *343*(6178), 1436–1437.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Brodie, E., Cowling, E., Nissen, N., Paine, A. E., Jochum, V., & Warburton, D. (2009). *Understanding participation: A literature review*. *Pathways through participation*.

Brossard, D., Lewenstein, B., & Bonney, R. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education*, *27*(9), 1099–1121. https://doi.org/10.1080/09500690500069483

Chammas, A., Quaresma, M., & Alvão, C. M. (2015). A Closer Look On The User Centred Design. *Procedia Manufacturing*, *3*, 5397–5404. https://doi.org/10.1016/j.promfg.2015.07.656

CITI-SENSE. (2016). Deliverable D 6.4. Final report on methodology.

Cooper, C. B., & Lewenstein, B. (2016). Two Meanings of Citizen Science. In D. Cavalier & E. B. Kennedy (Eds.), *The Rightful Place of Science: Citizen Science* (pp. 51–62). Tempe, AZ: Consortium for Science, Policy & Outcomes.

Crain, R., Cooper, C., & Dickinson, J. L. (2014). Citizen Science : A tool for integrating studies of human and natural systems. *Annual Review of Environment and Resources*, *39*, 641–665. https://doi.org/10.1146/annurev-environ-030713-154609

Dehnen-Schmutz, K., Foster, G. L., Owen, L., & Persello, S. (2016). Exploring the role of smartphone technology for citizen science in agriculture. *Agronomy for Sustainable Development*, *36*(2), 25. https://doi.org/10.1007/s13593-016-0359-9

Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Martin, J., … Purcell, K. (2012). The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment*, *10*(6), 291–297. https://doi.org/10.1890/110236

Environment and Health Fund, & Ministry of Health. (2017). *Environment health in Israel 2017*.

Eveleigh, A., Jennett, C., Blandford, A., Brohan, P., & Cox, A. L. (2014). Designing for dabblers and deterring drop-outs in citizen science. *Proceedings of the 32nd Annual ACM Conference on Human Factors in Computing Systems*, 2985–2994. https://doi.org/10.1145/2556288.2557262

Fischhoff, B. (2013). The sciences of science communication. *Proceedings of the National Academy of Sciences*, *110*(3), 14033–14039. https://doi.org/10.1073/pnas.1213273110

Golumbic, Y. N., Baram-Tsabari, A., & Fishbain, B. (2016). Increased knowledge and scientific thinking following participation of school students in air-quality research. In *Proceedings of Indoor Air 2016*.

Golumbic, Y. N., Orr, D., Baram-Tsabari, A., & Fishbain, B. (2017). Between Vision and Reality: A Case Study of Scientists' Views on Citizen Science. *Citizen Science: Theory and Practice*, *2*(1), 1–13. https://doi.org/https://doi.org/10.5334/cstp.53

Graham, E. A., Henderson, S., & Schloss, A. (2011). Using mobile phones to engage citizen scientists in research. *Eos, Transactions American Geophysical Union*, *92*(38), 313–315. https://doi.org/10.1029/2011EO380002

Guest, G., MacQueen, K. M., & Namey, E. E. (2011). *Applied Thematic Analysis*. Washington, D.C.: SAGE Publications Inc.

Haklay, M. (2013). Citizen Science and Volunteered Geographic Information – overview and typology of participation. In D. Sui, S. Elwood, & M. Goodchild (Eds.), *Crowdsourcing Geographic Knowledge: Volunteered Geographic Information (VGI) in Theory and Practice* (pp. 105–122). Berlin: Springer Netherlands.

Haywood, B. K. (2016). Beyond Data Points and Research Contributions: The

Personal Meaning and Value Associated with Public Participation in Scientific Research. *International Journal of Science Education, Part B*, *6*(3), 239–262. https://doi.org/10.1080/21548455.2015.1043659

Jennett, C., Kloetzer, L., Schneider, D., Iacovides, I., Cox, A., Gold, M., … Talsi, Y. (2016). Motivations, learning and creativity in online citizen science. *Journal of Science Communication*, *15*(3), A05.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed Methods Research: A research paradigm whose time has come. *Educational Researcher*, *33*(7), 14–26.

Kobernus, M. J., Berre, A. J., Gonzalez, M., Liu, H. Y., Fredriksen, M., Rombouts, R., & Bartonova, A. (2015). A Practical Approach to an Integrated Citizens' Observatory: The CITI-SENSE Framework. In *Proceedings of the workshop 'Environmental Information Systems and Services—Infrastructures and Platforms 2013' (ENVIP 2013)*.

Krueger, R., & Casey, M. (2014). *Focus groups: A practical guide for applied research*. Thousand Oaks, California: Sage publications.

Lazar, J. (2001). *User-centered Web development*. Boston: Jones and Bartlett Computer Science.

Lipkus, I. M., & Hollands, J. G. (1999). The visual communication of risk. *JNCI Monographs*, *1999*(25), 149–163. https://doi.org/10.1093/oxfordjournals.jncimonographs.a024191

Mao, B. J., Vredenburg, K., Smith, P. W., & Carey, T. (2005). User-centered design practice. *Communication of the ACM*, *48*(3), 105–109.

May, A., & Ross, T. (2018). The design of civic technology: factors that influence public participation and impact. *Ergonomics*, *61*(2), 214–225. https://doi.org/10.1080/00140139.2017.1349939

Ministry of Environmental Protection. (2014). *Emissions and air quality in Haifa bay area, update as to December 2014*. Retrieved from http://www.sviva.gov.il/YourEnv/CountyHaifa/HaifaBay/Documents/haifabayair2014.pdf

Ministry of Environmental Protection. (2015). *Air Pollution in Haifa Bay*. Retrieved from http://www.sviva.gov.il/English/env_topics/IndustryAndBusinessLicensing/Haifa-Bay-Industrial-Zone/Pages/Air-Pollution-in-Haifa-Bay.aspx

Muller, M. (2003). Participatory design: the third space in HCI. In A. Sears & J. A. Jacko (Eds.), *Human-computer interaction: Development process* (pp. 165–181). Boca Raton, FL: CRC Press.

Myers, T. A., Maibach, E., Peters, E., & Leiserowitz, A. (2015). Simple Messages Help Set the Record Straight about Scientific Agreement on Human-Caused Climate Change: The Results of Two Experiments. *PLOS ONE*, *10*(3), e0120985. https://doi.org/10.1371/journal.pone.0120985

National Academies of Sciences Engineering and Medicine. (2018). *Learning*

Through Citizen Science : Enhancing Opportunities by Design. Washington, DC: National Academies Press. https://doi.org/10.17226/25183

Norman, D. A., & Draper, S. W. (1986). *User-Centered System Design: New Perspectives on Human-Computer Interaction.* Hillsdale, NJ: Lawrence Earlbaum Associates.

Preece, Jennifer. (2016). Citizen Science: New Research Challenges for Human–Computer Interaction. *International Journal of Human-Computer Interaction*, *32*(8), 585–612. https://doi.org/10.1080/10447318.2016.1194153

Preece, Jenny. (2000). *Online communities : designing usability, supporting sociability*. New York: John Wiley.

Prestopnik, N., Crowston, K., & Wang, J. (2017). Gamers, citizen scientists, and data: Exploring participant contributions in two games with a purpose. *Computers in Human Behavior*, *68*, 254–268. https://doi.org/10.1016/j.chb.2016.11.035

Ren, Y., & Kraut, R. E. (2014). Agent-based modeling to inform online community design: impact of topical breadth, message volume, and discussion moderation on Member Commitment and contribution. *Human–Computer Interaction*, *29*(4), 351–389. https://doi.org/10.1080/07370024.2013.828565

Riesch, H., & Potter, C. (2014). Citizen science as seen by scientists: Methodological, epistemological and ethical dimensions. *Public Understanding of Science*, *0963662513*(23), 107–120. https://doi.org/0963662513497324

Rotman, D., Preece, J., Hammock, J., Procita, K., Hansen, D., Parr, C., … Jacobs, D. (2012). Dynamic Changes in Motivation in Collaborative Citizen-Science Projects. *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work*, 217–226. https://doi.org/10.1145/2145204.2145238

Rottenberg, Y., Zick, A., Barchana, M., & Peretz, T. (2013). Organ Specific Cancer Incidence in an Industrial Sub-district : a Population-based Study with 12 Years. *American Journal of Cancer Epidemiology and Prevention*, *1*(1), 1–10.

Sagy, O., Golumbic, Y. N., Abramsky, H., Benichou, M., Atias, O., Manor, H., … Angel, D. (2019). Citizen Science: An Opportunity for Learning in the Networked Society. In Y. Kali, A. Baram-Tsabari, & A. M. Schejter (Eds.), *Learning in a Networked Society (LINKS)*. Springer Computer Supported Collaborative Learning (CSCL) series.

Sauermann, H., & Franzoni, C. (2015). Crowd science user contribution patterns and their implications. *Proceedings of the National Academy of Sciences*, *112*(3), 679–684. https://doi.org/10.1073/pnas.1408907112

Senabre, E., Ferran-Ferrer, N., & Perell, J. (2018). Participatory design of citizen science experiments. *Comunicar*, *26*(54), 29–38.

Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., … Bonney, R. (2012). Public participation in scientific research : A framework for deliberate design. *Ecology and Society*, *17*(2). https://doi.org/10.5751/ES-04705-170229

Silvertown, J. (2009). A new dawn for citizen science. *Trends in Ecology & Evolution*, *24*(9), 467–471. https://doi.org/10.1016/j.tree.2009.03.017

Sinha, G., Shahi, R., & Shankar, M. (2010). Human Computer Interaction. In *3rd International Conference on Emerging Trends in Engineering and Technology* (pp. 1–4). https://doi.org/10.1109/ICETET.2010.85

Soleri, D., Long, J. W., Ramirez-Andreotta, M., & Eitemiller, R. D. (2016). Finding pathways to more equitable and meaningful public-scientist partnerships. *Citizen Science: Theory and Practice*, *1*(1), 1–11. https://doi.org/http://doi.org/10.5334/cstp.46

Sprinks, J., Wardlaw, J., Houghton, R., Bamford, S., & Morley, J. (2017). Task Workflow Design and its impact on performance and volunteers' subjective preference in Virtual Citizen Science. *International Journal of Human-Computer Studies*, *104*, 50–63. https://doi.org/10.1016/J.IJHCS.2017.03.003

Stebbins, R. A. (2007). *Serious leisure: A perspective for our time*. New Brunswick, New Jersey: Transaction Publishers.

Storksdieck, M., Shirk, J. L., Cappadonna, J. L., Domroese, M., Göbel, C., Haklay, M., … Vohland, K. (2016). Associations for citizen science: regional knowledge, global collaboration. *Citizen Science: Theory and Practice*, *1*(2). https://doi.org/10.5334/cstp.55

Sturm, U., Schade, S., Ceccaroni, L., Gold, M., Kyba, C., Claramunt, B., … Luna, S. (2018). Defining principles for mobile apps and platforms development in citizen science. *Research Ideas and Outcomes*, *4*, e23394. https://doi.org/10.3897/rio.4.e23394

Sullivan, B. L., Aycrigg, J. L., Barry, J. H., Bonney, R. E., Bruns, N., Cooper, C. B., … Kelling, S. (2014). The eBird enterprise: An integrated approach to development and application of citizen science. *Biological Conservation*, *169*, 31–40. https://doi.org/10.1016/j.biocon.2013.11.003

Swann, C. (2002). Action Research and the Practice of Design. *Design Issues*, *18*(1), 49–61. https://doi.org/10.1162/07479360252756287

Thomas, D. R. (2006). A general inductive approach for snalyzing qualitative evaluation data. *American Journal of Evaluation*, *27*(2), 237–246. https://doi.org/10.1177/1098214005283748

Wald, D. M., Longo, J., & Dobell, A. R. (2016). Design principles for engaging and retaining virtual citizen scientists. *Conservation Biology*, *30*(3), 562–570. https://doi.org/10.1111/cobi.12627

Wiggins, A., & Crowston, K. (2011). From Conservation to Crowdsourcing: A Typology of Citizen Science. *2011 44th Hawaii International Conference on System Sciences*, 1–10.

Wiggins, A., & Crowston, K. (2015). Surveying the citizen science landscape. *First Monday*, *20*(1), 1–12.

Wilkinson, C. R., & De Angeli, A. (2014). Applying user centred and participatory design approaches to commercial product development. *Design Studies*, *35*(6), 614–631. https://doi.org/10.1016/j.destud.2014.06.001

Yadav, P., & Darlington, J. (2016). Conceptual Frameworks for Building Online Citizen Science Projects. *Human Computation*, *3*(1), 213–223. https://doi.org/10.15346/hc.v3i1.12