Citizen Science Method

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Definition

The “citizen science” term is used for environmental monitoring projects or an ongoing program of scientific work in which individual volunteers or networks of volunteers, many of whom may have no specific scientific training, perform or manage air quality research-related tasks such as observation, measurement, data validation, or computation. It reflects a contemporary understanding of science that allows societal engagement through participatory methods. The term "citizen science method" for knowledge transfer purposes can be defined as the four-element study design consisting of *preparation, measurements, data analysis,* and *scientific support* components for societal engagement. Each of the four elements is a prerequisite for involving various citizen communities in scientific processes. The method for citizen science is therefore valid if all four of the elements are integrated into the study design.

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1. Introduction

The first recorded use of the term citizen science (CS) in the form that we currently use can be traced to three decades ago, according to the researchers of the Oxford English Dictionary. The term appeared in an issue of the MIT Technology Review from January 1989[1]. CS involves public participation in scientific exploration and possibly other activities designed to advance the public’s understanding of their environment, including local air quality. CS initiatives that focus on air quality often use low-cost sensors to measure concentrations of different pollutants. A wide variety of small, portable, and lower-cost monitoring devices are being developed by industry, universities, and individuals to potentially enhance air quality monitoring means. Low-cost sensor networks make it possible to monitor most of the hazardous pollutions in outdoor air that have been applied for various CS projects in the past years in Europe and overseas[2]. Although CS has been around for almost three decades, the clear definitions and research set-ups vary among the scientific community[1].

2. State-of-the-Art of Citizen Science

The “citizen science” term is used for air quality monitoring projects or an ongoing program of scientific work in which individual volunteers or networks of volunteers, many of whom may have no specific scientific training, perform or manage air quality research-related tasks such as observation, measurement, data validation, or computation[3]. It reflects a contemporary understanding of science that allows societal engagement through participatory methods. Involving various citizen communities into scientific processes can create spatially and temporally very complex, and in part, completely new and novel data sets that require both web-based and analog infrastructures as well as new lightweight wearable monitoring devices.

A project called “CurieuzeNeuzen Vlaanderen (Curious Noses Flanders)” launched in 2018 in Europe. It has been described as “the largest citizen science project on air quality to date”[4]. The initiative’s goal was to create a detailed map of nitrogen dioxide (NO_2) concentrations in Flanders (the northern region of Belgium), both in urban and rural areas. Participants received prior information about the project via media and could sign up to participate for a small fee (10 Euro). Each participant installed a simple, standardized measurement device on a street-facing window of their house, apartment, or building. Two diffusion tubes determined the mean concentration of nitrogen dioxide (NO2) in the ambient air over one month (May 2018). Quality assurance was provided, and the data collected from the diffusion samplers were scientifically controlled and calibrated with NO2 measurements at reference monitoring stations operated by the Flemish Environment Agency (VMM). The community collected the data and did not scientifically validate or analyze NO2 data themselves. Scientific support in the project data analysis part was not executed as the data were collected to help test a computer model for air quality in the region.

The Health and Environment Alliance (HEAL) conducted a measurement project with passive samplers as part of its “Healthy Air, Healthier Children” campaign. Fifty elementary schools in Warsaw, Berlin, London, Paris, Madrid, and Sofia participated in HEAL’s air quality survey inside and outside elementary school from March to May 2019, monitoring particulate matter (PM), nitrogen dioxide (NO_2), and carbon dioxide (CO_2)[5]. The air quality crowdsourcing study design approach started with a one-day seminar where each participating school was visited by a project representative, to explain the activity and then monitor PM and CO_2 concentrations for a period of ± 20 min. Project partners along with teachers and often the help of students installed the diffusion tubes. In the second phase of the study design, the measurements took place outside the school entrance and inside the schools’ classrooms. The measurements were performed for 3–4 weeks using diffusion tubes which were provided to each participating school together with a project poster board. Data analysis was carried out by researchers. Once again, as in “CurieuzeNeuzen Vlaanderen”[4], the interpretation of the air quality measurement weeks results was not carried out by the wider community but by project scientists[5].

An example where the community could carry out air quality measurements, as well as data analysis, is “hackAIR”. This CS approach was an open technology platform to access, collect, and improve information on air quality in Europe[6]. It was created by six European organizations as part of an EU-funded project on Collective Awareness Platforms for Sustainability and Social Innovation (2016–2018). Since 2018, the same low-cost diffusion tubes can be used to contribute with PM data collection to a “senseBox” project that took over the userbase from “hackAir” once the project funding ended in 2018. The project “senseBox” was developed at the Institute for Geoinformatics at the University of Münster as part of a research project funded by the German Federal Ministry of Education and Research (BMBF). The senseBox is a do-it-yourself kit for stationary and mobile sensor stations and aims to reach as many citizens as possible. The “senseBox” is intended to enable users such as schools and student labs to integrate the contents of the “senseBox” into their curriculum. The “hackAir” (later “senseBox”) study design consists of four elements. Firstly, information was shared with the project community on how to build your diffusion tubes in workshops with project scientists. After that, the participants could carry out (unlimited time) PM measurements and thirdly validate and analyze their data. These two CS initiatives differ from the first two CS projects explained above by the non-passive approach of just air quality data gathering. Scientific support was provided in “hackAir” and is provided in “senseBox” CS projects, respectively, as the fourth element during the measurement phase and data interpretation phase.

The CS project “CAPTOR” was launched in 2016. Using low-cost measurement devices, citizens supported tropospheric ozone monitoring in three European testbeds. Metal oxide and electrochemical sensing devices with Arduino or Raspberry Pi. Sensor validation and calibration were carried out at regulatory-grade air quality monitoring stations in each of the testbeds[7]. This CS project offered a passive participation option for the citizens. The devices themselves were installed by project team members. “CAPTOR” hosts were provided with background information on ozone in informal conversations with the project team and via the “CAPTOR” project website, but consuming this information was voluntary. The sensors were installed by scientists, and the measurements took place for 2–3 years[7].

In 2017, a knowledge transfer and co-creation project WTimpact was launched. WTimpact aimed to find out more about what citizens learn in such projects and how citizen science projects can be optimally designed. Part of WTimpact was the "Luft-Leipzig"[8] project that aimed at air quality awareness building and for crowdsourcing mobile air quality measurements. Citizens had to participate in workshops and an online project platform with tutorials launched. Each volunteer was lent the PM10 (particulate matter) and BC (black carbon) sensor set for one week for carrying out measurements. No financial commitment was requested from the participants. The project offered an active approach for citizens. The result was a dataset of more than three million air eBC and PM related data points that enabled the scientist to plot the air quality map of Leipzig and develop further CAIRDIO models.

A controversial CS study design approach to “CAPTOR” is the “luftdaten.info” design where sensing and air quality mapping rely heavily on community active participation. The CS project is the project that is led by “OK Lab Stuttgart” for PM measurement. This project development started in 2014. Citizens install self-built measuring devices on the outside wall of their house that they finance themselves (approximately 40 euro). From the transmitted data, luftdaten.info generates a constantly updating particulate matter map. The design starts with workshops where participants obtain the necessary information on data collection protocols, network specifics, and know-how on sensor development. The measurement phase for the PM sensing community in unlimited and scientific support is offered in form of community gatherings as well as by online means[6].

A CS example from the United States with a four-element study design is “communityAQ”; the project has been active since 2009. It allows participants to monitor air quality at stationary sites with the community air monitor (CAM) or on-the-go with the mobile personal air monitor (PAM). The CAM and PAM provide participants with complementary technology for any air-monitoring scenario. The data collection process is supported with smartphone apps and interactive online data visualizations. Air pollution data collected by communities and students from both mobile indoor and outdoor surveys and stationary gauges are displayed on maps and in graphs. Outreach programs have reached approximately 200,000 students at more than 350 schools. Through these programs, students have been responsible for uploading more than 12 million ozone measurements and more than 2000 mobile treks. The community can download their data and compare it to others’ measurements. Scientific support is available throughout the process via a platform where there are Moodle programs for study and awareness-building purposes[9].

3. Citizen Science Method

Citizen science project method for mitigating climate warming and fighting air pollution is dependent on the project goals. The above-listed air-quality-related citizen science initiatives present an overview of various study designs all for the goal of better air quality and for fighting global warming. Nevertheless, there are various channels for those ambitious goals. In the case of “CAPTOR”, the project goal was not to educate the community. The “CAPTOR” aimed at advancing existing knowledge on the usage of low-cost sensors for ozone measurement and to learn about the impact of the involvement of citizens as sensor hosts. Similarly, the “CurieuzeNeuzen Vlaanderen” aimed at creating a detailed pollution map and using the citizens just as sensor hosts. Knowledge transfer was not the goal of these two CS projects. If, however, the aim of the CS initiative is awareness building and knowledge transfer, a more excessive involvement of the community into data analysis and interpretation processes is presented by “hackAir”, “senseBOX”, “Healthy Air, Healthier Children”, "Luft-Leipzig", and “communityAQ”. In the latter case, information dissemination (workshops or online manuals), citizen measurement phases, data analysis and validation, and scientific support are necessary CS study design elements. Based on the current air pollution CS projects state-of-the-art, the study design for knowledge transfer purposes is summarized below.

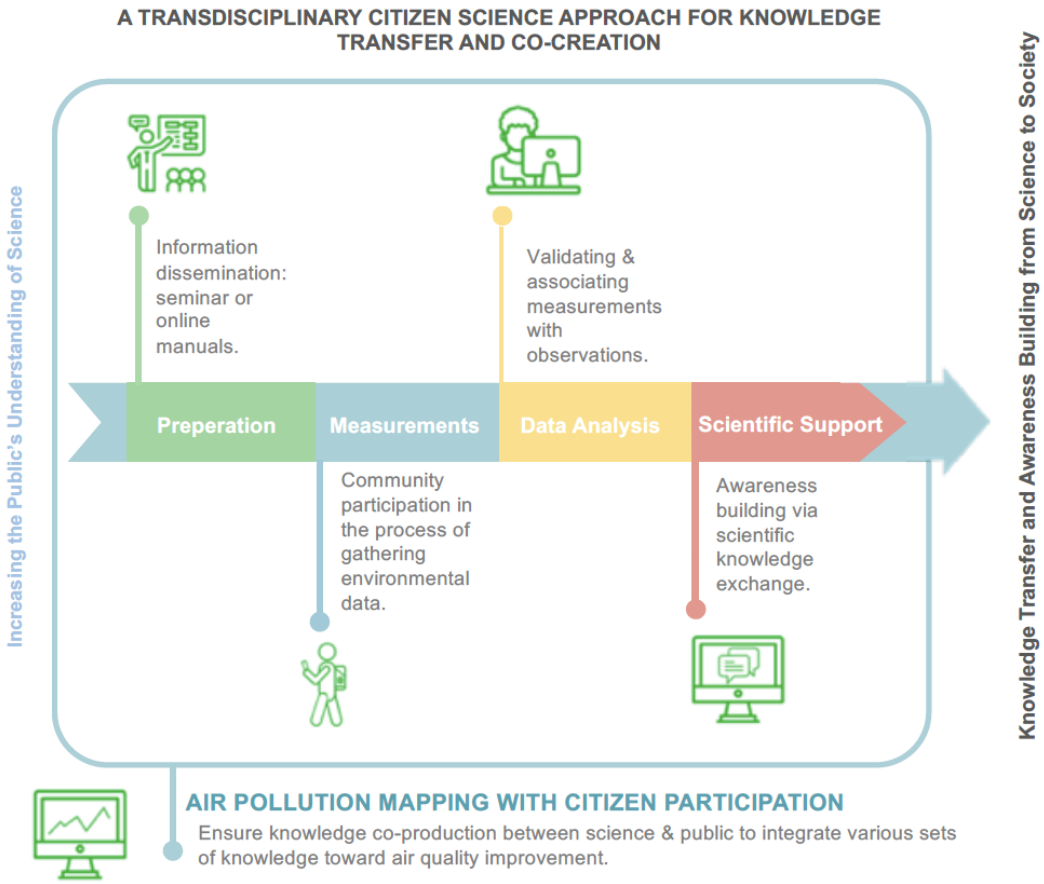

Figure 1. The four-element-CS air quality sensing study design recommended by state-of-the-art method aiming at knowledge transfer.

The limitations for creating a commonly accepted method are the various scientific goals of knowledge transfer projects. To date, no common definition or method for CS exists as many types of infrastructures exist with different functionalities[5]. It is important to note that the aims of the project can vary, and the above-presented study design can be modified according to individual CS project needs. Most CS initiatives for raising public awareness include each of the four elements that were presented in detail by the Luft-Leipzig case study. The study design should start with public preparation element where information is disseminated in the form of workshops (in the case of "Healthy Air, Healthier Children" campaign, "senseBOX", "luftdaten.info", "hackAir", Luft-Leipzig, and the USA example—"communityAQ") or the SLCP, and air quality-related information is disseminated via online channels only ("CurieuzeNeuzen Vlaanderen"), and it is possible that consuming the information is voluntary ("CAPTOR"). However, a certain amount of information has to be made available for the public to carry out CS projects.

The second common element in almost all CS projects is the element that involves public participation in scientific exploration. The duration of the measurements phase can last from one week (Luft-Leipzig) to several years ("CAPTOR"), and this element of the study design has to be designed for specific project goals. It must be noted that it is both possible to offer the sensors for no costs (e.g., "CAPTOR" or Luft-Leipzig) or for low costs ("CurieuzeNeuzen Vlaanderen" 10 euro or "luftdaten.info" approximately 40 euro).

The third element is data analysis, which can be carried out by community and/or scientist. If the goal of the study is to educate the public about SLCP and air quality and to contribute to knowledge transfer based on state-of-the-art methods, the public is in one way or another integrated into data analysis processes. In other words, the community can visualize, download, validate, edit, and/or compare their observations with others or at least carry out one of the mentioned functions.

The fourth element common in study designs for CS knowledge transfer studies is the scientific support component. This is defined by scientific work with the community data that is made available for the citizens so new knowledge can be generated. In the "CAPTOR" or "CurieuzeNeuzen Vlaanderen" CS project, the scientific support element consisted of experts validating the data and making the SLCP and air-quality-related data available with the support of mathematical modeling or even developing advanced AI algorithms based on community data and presenting it to the public without requesting citizen commitment to modeling or AI algorithms development. Alternatively, active community involvement in analysis and data interpretation can be integrated into the fourth element as well as performed in "senseBOX" or "communityAQ". There, expert assistance (scientific support) is offered in the form of interpreting the air-quality-related data. The complexity of the scientific goals determines how much citizens can be involved in the final scientific element. Due to data protection laws, it must be noted that in EU the individual GPS data publishing is not allowed, and therefore joint results can be presented in reports and publications and web-outlets.

If community participation should be wide-reaching and people from various backgrounds are targeted, developing advanced air quality AI algorithms or implementing mathematical modeling together with the public could be an extensive resource. Therefore, the state-of-the-art of air quality CS research presents various opportunities for scientific support and data modeling or interoperations element, which nevertheless is part of each air-quality-related CS initiative.

For future research, it is suggested to develop the four steps further, more in detail, and to specify each step for various scientific goals. For example, if the goal is not knowledge transfer and data curation with citizen participation, the concluded method of this study should be validated by setting up a case study and by drawing conclusions based on the case study results if the four steps are enough or too much for achieving specific scientific goals. Nevertheless, for a common definition of a CS method, it is important to make sure that the process is applicable beyond a specific case study.

4. Conclusions

The active role of citizens and their direct involvement is essential to address climate change. Changes in citizen's behaviors toward more sustainable patterns can happen through knowledge transfer, awareness building, citizen science, observation and monitoring of their environmental impacts, and civic involvement[10]. Bridging policy and individual action to mitigate climate change via emission reduction is the key[11].

The four-element study design for the CS method definition is presented above in **Figure 1**. With the four elements, it is possible to contribute to SLCP mitigation science and knowledge transfer alike. This study design is suggested for forthcoming CS initiatives aiming at knowledge transfer and SLCP mitigation. As the international CS community is in the process of defining public participation in scientific projects [12], studies contributing to defining the design and methods of a specific area of focus (e.g., air quality and SLCP mitigation) contribute to further improving the value of CS. Establishing criteria and guidelines for a scientific topic related CS research set-ups helps ensure that CS projects are rigorous, help the field flourish, and, where applicable, encourage policymakers to take CS project data and results seriously. This paper contributes to science with a novel four-element study design for public involvement in SCLP mitigation knowledge transfer projects that can be applied beyond the Luft-Leipzig case study.

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Keywords

knowledge transfer;short-lived climate pollutants;air quality;sustainability