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Citizen Science: How to unleash potentials of new data collection?

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Abstract

Citizen Science has increased in popularity among universities and citizens, particularly concerning health issues, biodiversity in nature, water management, etc. The paper characterizes citizen science, in particular what the core intentions are and how it relates to specific approaches, like citizen sensing. Next, the paper highlights the potentials of citizen science, but also pays attention to reasons for a modest acceptance. A large citizen science project in Belgium – Curious Noses – and smaller local health projects in England serve as examples. Next, in order to progress with successful development of citizen science, attention shifts to what success of citizen science would encompass, given direct and indirect effects, and what factors may influence success.

1. Introduction

Citizen science can be described as the active participation of citizens (lay-people) in scientific and engineering research and monitoring, by targeting data collection and knowledge production. Accordingly, a set of methodologies is used in collecting, processing, and to a certain extent analysis of the data e.g. increasing detail in place (scale) and time, among others to enable improving results of problem definition and of modelling often at university (Den Broeder et al., 2017; CuriousNoses, 2019; Fraisl et al., 2022). The minimum requirements to make measurement activity being citizen science can be seen as: collaborative measurement by lay-people according to quality rules of science. Other values/characteristics coined so far in citizen science approaches include: active citizen participation, democratic, open, providing evidence-based underpinning, citizen empowerment, transdisciplinary, and networked (ICT and sensor enabled).

Citizen Science has multiple benefits. It is an efficient way to collect and process data. First, a group of citizen scientists that each do a little work, can collect a lot more data in a much smaller timeframe than any researcher or research-group can gather in the same timeframe. Secondly, citizen scientists collect among others from places that can be hard to reach for researchers, like backyards or schoolyards. Thirdly, citizen science provides great opportunities to test new technologies or innovations on a larger scale. In a *broader* conceptualization, citizen science also includes identifying and motivation of research questions (influencing the direction of research), developing scientific hardware and software to support measurement, and participation in design of complex solutions to the measured problem situations (Shanley et al., 2019). In a most comprehensive approach, the European Commission's White Paper (2015) posits that there is no single definition when citizens actively contribute to science either with their intellectual effort or surrounding knowledge, or with their tools and resources.

With regard to subject matter, many early citizen science projects are in bio-diversity research, like monitoring bees for the sake of human subsistence (Hallow et al. 2015; Cooper et al. 2017), but increasingly also in research of living quality of urban places (monitoring of air quality and noise, and other annoyance) and of public health in city quarters. Accordingly, as several more recent studies demonstrate, citizen science may help to provide the evidence-base to inform a wide range of management and public policy decision making at local levels.

No matter the subject concerned, participative measurement by citizens is faced with several challenges which sometimes turn out to be points of concern. These points include management of the campaign, objective of the campaign, its context, datatypes and methodology to be used, motivation of data collectors, validation and representativeness, visualization and reporting (Keseru et al., 2018; Van Geenhuizen and Berti Suman, 2021). Much depends on where the initiative and motivation for citizen science is rooted, which could be at university, at a group of citizens, or both.

Citizen science may also include what has been named *'citizen sensing'*, as a grassroots initiative. Accordingly, citizens organize themselves to start measuring in a situation in which they feel exposed to a certain risk and worry about health damage, but are not sufficiently understood and recognized by authorities or institutional actors causing the risk (Gabrys 2017; Berti Suman and Van Geenhuizen, 2019). As a more 'activist' type of citizen science, citizens often have composed their own measurement system (sensor-based). Accordingly, citizens utilize networked sensor technology in measuring their exposure to a risk on their own account, thereby challenging institutional data (Boulos et al. 2011) and inviting stakeholder that cause the risk, to respond to measurements. Citizen sensing illustrates that citizen science may not only be driven by collaboration but also by contestation (Meijer and Potjer, 2018).

2. Background and Diversity in Citizen Science

The background to the increased popularity of citizen participation in measurements is rooted in the following social and policy developments, and technology progress:

1. Recognition of increased complexity in understanding of problem situations and need for *new qualities* of local governance (services) (Ostrom 1990; Osborne 2016).
2. Democratization of *power* and shift to participatory problem definition and -solving (Ansell and Torfing 2016). This involves among others a stronger eye today on conflicts in urban planning (Herzog et al., 2024).
3. Democratization of *science* with increased contribution of citizens, e.g. agenda-setting, data-collection, and the move to Open Science (EC 2014; Hecker et al. 2018).
4. Larger societal role for universities in the so-called civic university (Goddard and Vallance 2013).
5. Users (citizens) as an important source of innovation: *user-centred innovation* (Von Hippel 2005, 2017).
6. Increased attention for Smart Cities. Such cities ideally provide high living quality by addressing public issues (opinions) via ICT-based solutions (digitalization, data-integration) on the basis of

multi-stakeholder and municipally-based partnerships (Manville et al. 2014; Caragliu and Del Bo 2018; Bauer et al. 2021).
7. Progress in (sensor) technology that enables measurements (mobile phone, apps, platforms, real time monitoring and sharing; situation aware sensors, and use of artificial intelligence).

More than two decades after the publication of Irwin's seminal book (Irwin 1995), an increasing awareness and use of citizen science by urban governments and multilateral organizations can be observed in addressing both scientific and societal challenges (e.g. Nascimento et al. 2017). Governments in the US and Europe, for example, have incorporated citizen science and crowdsourcing as part of their Open Science, Open Innovation, Open Government, and/or Open Data initiatives (e.g. OECD, 2016; EC, 2016). The overall diversity within citizen science, like in domains, leading stakeholder, degree of openness, extent to which citizens are also involved in data interpretation and searching for solutions, and stakeholder complexity of the problems concerned, is increasingly recognized. This also holds for the need to investigate this diversity in interpretations in several domains and stakeholder complexity etc. (e.g. Hakley et al., 2021).

To date, citizen science and its results are not yet fully accepted in several circles, like academic science and public policymaking. The points *casting doubt* include: 1) *Validity* of indicators used, validity of measurement, data processing and - communication (quality of cell-phone, apps platforms, calibration, processing) (Shanley et al., 2019), 2) *Democratic content:* participation should include more than 'usual suspects' (all layers of affected citizens needed). 3) *Capability level of citizens to provide deeper information* could be limited (as lay people/volunteers). 4) *Overall effectiveness*: it is uncertain whether better quality of data, better understandings, better solutions, happier citizens, can be achieved at all, and at reasonable cost levels. What may help is strengthening of organizational embedding (e.g. within municipality) and improving of visibility of citizen science projects.

3. Two contrasting case studies

The first citizen science project to be discussed here (CuriousNoses) took place in 2018, aimed at measuring nitrogen dioxide (NO_2) in ambient air in the city of Antwerp (region of Flanders, Belgium) (Meysman and De Cramer, 2018; Voordeckers et al., 2021). Measurement took place using a standardized device (tubes) that were fixed by inhabitants on a street-facing window of their houses - over one month (May 2018). Inhabitants paid 10 Euro to gain the device and they delivered the tubes after the measurement. The initiators of this citizen science project included the University of Antwerp, De Standaard, and the Flemish Environmental Organisation. The results of this project are well-accepted and stand out by very fine-grained data (not possible to achieve otherwise), being unprecedented in the world. Also validity of measurement turned out to be high, with an estimated 96 percent of 20.000 measurements being valid. After additional checks, 89 percent was taken in further use. Aside from an overview of streets and roads' scores, several high-level spots were identified, among others the so-called urban street canyons, with some of them exceeding international standards. At the same time, traffic policy and traffic services firms in the city delved deeper into avoiding air pollution, for example, by applying dosage rules in traffic circulation (using traffic lights). A challenge here remains active participation by citizen scientists to improve the situation, other than fixing and removing the tubes from their houses, and adjusting own car-use in travel behaviour.

While the first case study is large in scale, fully backed by university support, including processing of data, the second case study is much smaller and deals with location-based healthcare for elderly. The projects are performed in medium-sized and large cities in England, often in relatively deprived quarters. The aim is to identify healthcare deficits in elderly's community (area) and also to propose solutions (Wood et al. 2023). Usually a two/three steps approach is used in data-collection i.e. elderly people are asked which shortage they perceive in local healthcare, followed by an invitation to participate in co-production workshops aimed at developing solutions together with community stakeholders (including medical professionals) and researchers. Researchers also collect information through in-depth ethnographic studies among elderly citizens. The latter type of study encompasses close observation and description how elderly behave with a focus on walking, physical exercise, food intake etc. These steps serve to design interventions, both in the quarters concerned and the city as a whole, to improve the local healthcare situation, including action plans.

Challenges in these location-based citizen health projects turn out to be threefold, i.e. to reduce response-biases due to majorities of "white-English-female" participants, to diminish overestimation of citizens' potentials in dealing with specific social media tools or other e-tools to motivate prior training, and lack of sufficient time and resources to take full benefit of results, like in designing and testing realistic action plans (e.g. Wood et al. 2023).

We close this part with the general remark that citizen science results are not yet fully accepted in science and in policymaking. The reason for these are the following, already somehow addressed in the above case-studies, but also including new ones:

1. Remaining validity issues in measurement, data processing and- communication (quality of cell-phone, sensors, apps platforms, calibration, positioning of instruments; processing of data), e.g. Droste et al. (2024).
2. Democratic content: participation should include more than 'usual suspects'. All layers of citizens in the city-quarters need to participate in preventing exclusion.
3. Capability levels of citizens to provide deeper information turn out to be low (as lay people/volunteers); the same may hold true for handling specific e-tools.
4. Overall effectiveness: it is uncertain whether better quality of data, better understandings, better solutions, happier and healthy citizens, can be achieved at all, and at reasonable cost levels.
5. Not intended negative impacts on citizens may encompass overburdening (or over-sensitization) particularly in poor areas, decrease of self-reliance if projects are abandoned unexpectedly due to lack of funding, demotivation to remain involved if the data-collection is time-consuming, a difficult tasks if there is mismatch between goals of citizens (e.g. requiring structural change) and actual data-collection; disillusion and volunteer fatigue if no impact or if no feedback received.
6. Not intended impacts may also emerge due to partially neglecting of local citizen knowledge and institutions (Walker et al. 2021) and due to disbelieve of citizen science data among other stakeholders, if results are against the latter's interests.

4. Wide range of additional advantages

In citizen science scientists and citizens (the public) and other stakeholders are brought together in a way that enables co-production of knowledge e.g. through environmental competency groups and community modelling. Apart from producing unique and socially relevant data, several additional advantages may be shaped. We mention the following advantages as indirect effects:

a. *Skills development among citizens*: citizens may engage in modelling (risks) with professional scientists, like in flood risks, but citizens may also learn from own data collection and interpretation, and change behaviour informed by their results, like in agriculture.
b. *Social capital formation*: between different stakeholders interpersonal *trust* may develop due to being involved in co-production of knowledge and due to appreciation of that local knowledge; also more social capital may arise due to feelings of own community connectedness, and of connectedness with university, agencies, etc.
c. *Empowerment*: raising awareness may occur among citizens on needs to eventually 'mistrust' official data and risk assessment, and take own initiatives (citizen sensing).

The above points in fact urge to answer the *question when citizen science can be considered a success?* We may tentatively posit that minimal success as a direct effect is the collection of good quality data among representative citizens (Keseru et al. 2017; Michels and De Graaf 2017), and that some of the above positive indirect effects have been realized, like social capital building and skills' development among citizens. At the same time, negative indirect effects need to have been avoided.

5. Concluding remarks

Citizen science, either science-driven or citizens-driven, have increased in popularity in the recent decades. What has received small attention but is improving today, is whether and how the results and processes of citizen science can be seen as a success and which key factors may influence success of citizen science, which has been seldom addressed. Accordingly, research is needed on factors driving quality of citizen science and quality of second-order impacts (see, Capdevila et al. 2020 for a literature review). Such factors may be categorized as follows:

1. Attributes of citizens involved : knowledge and experience on data-collection, awareness of environmental issues; citizen motivations (intrinsic motivation and motivation by external rewards).
2. Attributes of institutions involved: motivation (e.g. improved health-care for elderly; increase of water quality, data on larger scale and longer time); type of organization based on vision, mission, objectives; type of funding.
3. Processes/mechanisms driving interaction, participatory learning and valid measurement: stakeholder complexity; supporting structures and communication (including feed-back); protection of privacy (in case of health and real-estate ownership).

A better structured understanding of success and underlying factors may further increase legitimacy of citizen science, but heterogeneity in conceptualization and application in ecosystems remains a challenge to deal with. The European Commission (2022) already published a study revealing the differences between concepts and evidence demonstrating different (perceived) success of citizen science. For sure, there are interesting opportunities ahead of us in evaluation of effectiveness of citizen science, not only using in-depth action-based research but also large sample-based analysis of projects enabling statistical generalization of results that can be used in next generation citizen science projects.

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