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PRACTICE INSIGHTS

Co-creation in citizen science: sharing learnings and good practice from an indoor, airborne microplastics project

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Abstract

HOMEs was a citizen science exploratory project, aimed at investigating the presence of airborne microplastics in people's homes. Participants placed passive samplers in their homes, using low-cost microscopes to see and take pictures of their samples. The methods developed are promising, however there are a number of pitfalls to avoid and key considerations. This practice insight explores successful approaches and identifies barriers and limitations when embedding co-creation and participatory citizen science approaches to a research project. This piece focuses on the methods and engagement with participants, rather than on microplastics findings.

Keywords

Citizen science; Environmental communication; Public engagement with science and technology

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1 ▪ Context

1.1 ▪ *Citizen science and co-creation*

Citizen science is an increasingly popular research technique in environmental science [Fraisl et al., 2022; Cappa et al., 2022]; it is often viewed as an effective way of building engagement with the public as well as enabling the collection of data that could not otherwise be gathered (e.g., due to the scale, location, etc.) [Pocock et al., 2014]. As the number of environmental citizen science project increases [Kosmala et al., 2016] it is important to reflect and learn from each project to identify good practises and inform future projects. There has been an increase in co-creating within research projects [Stier & Smit, 2021], however it is still rare and noticeably hard to do well. The main gap is in fully co-created projects as the majority of citizen science relies on participation only for the collection, and sometimes the analysis of data [Kullenberg & Kasperowski, 2016]. This practice insight explores successful approaches, as well as those that did not work well within the HOMEs project, providing a transparent view of this particular type, and depth, of co-creation. It also identifies barriers and limitations to applying a participatory citizen science approach to a research project.

The term citizen science was coined in the 1990s by Alan Irwin in the UK and Richard Bonney in the US [Strasser et al., 2019]. The definition of citizen science has evolved alongside the development of new projects that try to engage participants with science and research. Currently, we can define citizen science as the voluntary participation of participants/non-scientists in research projects, usually while working together with experts and scientific organisations [Bonney, Cooper et al., 2009; Lucrezi et al., 2018]. In citizen science projects, participants can contribute to all manner of research: co-designing projects, collecting and interpreting data, defining problems and putting forward potential solutions. Participants' motivations for engaging in citizen science differ, ranging from a commitment to social justice and active citizenship, an increased awareness of environmental issues [Larson et al., 2020]. In general, citizen science can be categorized into three practices: contributory, collaborative or co-created [Bonney, Ballard et al., 2009]. Co-creation is perceived as the most participatory of the three practices, characterized as projects "designed by scientists and members of the public working together and for which at least some of the public participants are actively involved in most or all steps of the scientific process" [Bonney, Cooper et al., 2009, p. 11]. While empowering approaches have been documented [Cohen et al., 2017; Deutsch & Ruiz-Córdova, 2015] most citizen science projects today continue to take a contributory rather than community-led or co-created role, i.e., participants are usually assigned the roles of data gatherers and are less often involved in leading projects or setting aims and objectives [Science Communication Unit, 2013]. However, co-created projects can have vast impacts; by focusing on co-created and participatory methods, projects contribute to the democratization of citizen science [Sauermann et al., 2020], where the scientist's role shifts to co-designer and facilitator, with participants and civil society organisations taking more of a central role in co-creation and in defining and addressing problems [Senabre Hidalgo et al., 2021].

Environmental citizen science projects prioritize addressing real-world problems that matter to local participants [Phillips et al., 2019], a key motivator for their participation [Sardo et al., 2024]. In citizen science, co-creation fosters both knowledge and a sense of empowerment among participants [Sardo et al., 2024], promoting active, inclusive participation [Senabre

Hidalgo et al., 2021]. This approach involves researchers collaborating with stakeholders, including those affected by the research, throughout the study's design, execution, and analysis. It values diverse perspectives, strengthening research outcomes [Ramaswamy & Ozcan, 2018]. By engaging participants as co-researchers, co-creation emphasizes their concerns throughout the process. However, it also presents challenges, such as balancing social and scientific interests, varying knowledge levels, limited collective data interpretation [Senabre Hidalgo et al., 2021], and the need for researchers to value participants' input [Laggan et al., n.d.].

Recent calls to change the term have highlighted that 'citizen science' can be, in itself, problematic [Ellwood et al., 2023]. In particular, 'citizen' can be perceived as a word that excludes many and is perceived as not inviting to a diversity of community members [Cooper et al., 2021]. In this practice insight we therefore refer to 'participants', rather than 'citizen scientists. Another challenge in citizen science is power imbalance: while scientists involved in the projects receive payment, participants typically do not, even when they contribute in ways that could potentially be handled by paid researchers. This disparity can create a sense of inequity, as participants invest their time and effort without the financial recognition given to professional scientists. The National Institute for Health and Care Research argue that 'paying people for their involvement in research helps to support more equal partnerships between researchers and members of the public' [National Institute for Health and Care Research, 2024]. However, projects attempting to compensate participants for their contribution have found that the process of paying participants, though important and appreciated, was onerous and full of institutional barriers [Alizadehtazi et al., 2022].

In this piece we offer a critical reflection on challenges and opportunities of using co-creative citizen science, using the Homes Under the Microscope (HOMEs) project as case study to draw out lessons learned. A co-creative approach (in which residents shape the airborne microplastics sampling methods and collect data) can generate valuable data, improve sampling strategies and embed research and subject specific knowledge within communities. Understanding the strengths and weaknesses of these approaches through evaluatory mechanisms enables future participatory research projects to learn and build upon it.

1.2 ▪ *Collection and analysis of microplastics*

Microplastics are widespread in our surroundings, yet their occurrence in the air remains less comprehensively explored. Homes are likely primary contributors of airborne microplastics and microfibers to the environment, given the frequent use and storage of plastics and textiles [Yee et al., 2023; Torres-Agullo et al., 2022; Zhu et al., 2022]. Investigating their existence, concentration, and distribution in private homes proves challenging without the involvement of participants. Sampling by researchers within homes requires the trust and approval of residents and, to sample at scale, requires significant time and resource. In contrast, residents know their home environment well, and are not constrained in the same way as researchers.

Microplastics can be defined as "any synthetic solid particle or polymeric matrix, with regular or irregular shape and with size ranging from 1 μm to 5 mm" [Frias & Nash, 2019, p. 146]. They are regularly found across the biosphere, within marine and freshwater environments [Zarfl & Matthies, 2010] and soils [Yang et al., 2021]. Studies have also found microplastics in the air [Zhang et al., 2019] and it is now recognised that airborne microplastics exist in a wide range of outdoor environments including urban, rural and remote areas [Prata et al., 2020]. A handful of studies have also found airborne microplastics in the home environment [Prata et al., 2020; Torres-Agullo et al., 2022; Zhang et al., 2020], but there is a lack of data on typical concentrations and how this varies between different homes and rooms within homes, which is important in identifying particular sources and routes to exposure. Participatory co-produced citizen science projects can potentially overcome these limitations and represent a stepwise change in better understanding microplastics in homes.

2 ▪ Methodology

2.1 ▪ *The HOMEs project*

HOMEs was a multidisciplinary project that brought scientists, participants and representatives of textile industries together to develop a new way to measure microplastics in the home [Williams et al., 2023] and overcome the above microplastics research challenges. An exploratory citizen science project, HOMEs presented the first project we know of to involve participants in at-home airborne microplastic knowledge production, beyond simply collecting and returning of samples to research teams. The project aimed to count how many and what type of airborne microfibre particles there were in a wide range of different locations within homes.

HOMEs aimed to build an understanding of the range of airborne microplastic concentrations in people's homes. The project started during the COVID-19 pandemic, which meant there were restrictions in people's movement, as well as in access to people's homes. The team focused on co-creating and shaping a data collection and analysis method with participants, that could be used with ease and would work during the pandemic and alongside its fluctuating restrictions on movement. By running a pilot first (Phase 1), the team was able to identify any challenges and barriers and address them, before rolling out the piloted and refined sampling, analysis and reporting approaches to a larger audience (Phase 2, main phase). As an exploratory citizen science project, its novelty lied on having a participatory phase (the pilot) and a contributory crowdsourcing phase (the main phase).

Participants placed passive samplers (i.e. petri-dishes) in their homes and used low-cost microscopes to look at and take pictures of their samples, using a smartphone. They then uploaded the pictures to an online image processing tool, which automatically counted the number of microfibers as well as giving information on the fibre size, shape and colour. Finally, participants returned the samples to the laboratory where the research team undertook confirmatory analyses allowing participants to see what types of plastic and other fibres (if any) were present in their samples.

2.2 ▪ *The HOMEs approach*

The research team designed HOMEs based on lessons learnt from their previous projects engaging the public, such as WeCount.[1] In WeCount, participants were given low-cost traffic sensors that they had to assemble from Raspberry Pi components, install and attach to their

1. https://we-count.net.

windows at home [Sardo et al., 2022]. The evaluation of the project found that, perhaps surprisingly, technology had been both one of the reasons for some participants to join the project but, at the same time, created numerous barriers to their participation [Sardo et al., 2021].

In HOMEs, participants were asked to collect and measure airborne microplastics, in order to do this, they needed to be able to use the kit provided and follow the instructions with ease. Learning from the technological barriers identified in WeCount, the HOMEs approach was to run a pilot with highly engaged participants in an effort to break most technological barriers, with the view to then roll out the project to a larger audience. The pilot was characterised with greater engagement and some participant control, whereas the main phase was a more traditional "contributory" projects where participants had no input to project design, but could contribute in the project's selection process of locations in houses where samplers would be positioned to measure microplastics.

2.3 ▪ *Phase 1: pre-pilot*

A pre-pilot was not part of the initial plans, but early on the project it became evident that one was needed. Essentially, there was a need to be able to make all three components (sampling method, low-cost microscope and image processing tool) link-up effectively before testing by participants, to ensure that the participants-led testing was simple, achievable and affective.

During the pre-pilot phase, the team researched low-cost microscopes and microplastic analysis methods to enhance sample magnification for imaging and characterisation via image processing. No existing publications covered the use of affordable clip-on microscopes for microfiber characterisation. The team sought microscopes that were compact, inexpensive, and user-friendly for participants. Four low-cost microscopes were chosen for evaluation, based on cost, size, and ease of use. These underwent testing and evaluation by the project team and a small group of participants, primarily personal contacts, offering informal feedback.

During the pre-pilot, unexpected barriers were identified, such as certain microscopes being compatible only with specific smartphones. This reinforced the need to run an in-depth pilot. Additionally, some microscopes required specific apps or worked better on computers, adding complexity for participants. The HOMEs team emphasized the importance of selecting user-friendly equipment that doesn't rely heavily on additional technology like computers or specific apps. Needing access to a computer would exclude people without one, whereas needing to install an app is usually not well received by people who might not want extra apps or lack the storage to install one, as previously described by Damodaran [2021].

Another challenge was determining which part of the sample the images were taken from. It was assessed by the team, with input from pilot participants, that the centre of the grid would be as representative of fibre deposition as much as any other section. The pictures were therefore taken from the centre of the grid as this was easiest to image under the microscope without removing the grid from the dish and risking contamination, as fibre deposition was random over the surface of the grid.

2.4 ▪ *Phase 2: pilot*

The HOMEs pilot focused on co-creation, with participants involved in all main decisions. For this reason, the team needed a "highly engaged" group of participants that was willing to dedicate considerable amount of time to the project while being involved in several tasks (details in Table 1). The aim of the pilot was to collect input from participants to shape and refine the methodology for the main phase of the project. The research team worked in collaboration with the pilot participants, selecting microscopes, refining the instructions and shaping the online tool. Reflecting on these elements resulted in a simpler, more streamlined process: main phase participants would have access to only one microscope, simpler instructions and given only two Petri dishes. As a result, the time commitment needed from main phase participants was much lower than from pilot participants, as intended.

Following the pilot and sample collection, pilot participants were sent infographics summarising the results and how they had collectively shaped and contributed to the project.

2.5 ▪ *Phase 3: main phase*

As a result of the collaboration with pilot participants, the project was able to roll-out a refined process with a much larger number of participants. However, during this final phase, citizen scientists were only contributing as data collectors, a common approach traditionally taken by many citizen science projects [Science Communication Unit, 2013]. This however meant the project could involve "less engaged" participants, who were willing to take part but lacked substantial amounts of time to do so. Table 1 summarises the main decisions and who was responsible for gathering data to inform those decisions and for making the final call.

2.6 ▪ *HOMEs timeframe*

Here we describe the timeframe for the study and steps involved including the pre, indepth pilot and main phases. The pre-pilot phase lasted approximately six months, this gave time to fully test the kits and instructions, prepare the material and the project website. Recruitment for the pilot took two months, with the pilot running for approximately eight months. Many kits were delivered to residents by hand which enabled a local connection and deeper engagement but was time consuming. The recruitment for the main phase was open for four weeks, which was sufficient to meet our target number of participants (80–100). Participants measured microplastics for two weeks, but we provided a 4–6-week window to accommodate potential delays participants might had in starting the project. We aimed to provide participants with a pack 7–10 days after registration.

2.7 ▪ *Recruitment*

The study focused initially on Bristol (pre-pilot and pilot) and then on both Bristol and Bradford residents (main phase), this geographical focus meant that recruitment was targeted to residents in those towns. Recruitment was done through word of mouth, advertising to local environment networks and community action groups as well through the HOMES twitter site. We also created and distributed an advert that that was sharable through WhatsApp and Facebook so people could re-share. The recruitment was aided by pre-existing collaborations with Bristol Green Capital Partnership (BGCP) and Born in Bradford who have

Table 1. List of main decisions and responsibilities across the HOMEs project.

Challenge	*Details*	*Responsible for gathering data to inform decision*	*Responsible for making the final decision*	*Outcome*
How long to measure for?	Sampling method had never been used in this context. Research team needed to assess how long the sampling window should be to get a representative sample.	Pre-pilot participants	HOMEs team	Petri dishes collected microplastics for two weeks.
Which microscope to use?	Multiple potential microscopes available. Selection criteria were cost, size, and ease of use.	HOMEs team identified four potential microscopes. Pre-pilot participants tested and reviewed the four microscopes.	HOMEs team	Clip-on-to-phone microscope provided to all participants in main phase.
Which rooms to measure in?	Finding out which rooms people were most interested to get results from and where highest concentrations would be.	Pilot participants	Pilot participants	Bedroom identified as having highest concentrations, but participants encouraged to sample wherever was most accessible and convenient to them.
Evaluate instructions	Needed to create clear step-by-step instructions for participants.	Pre-pilot participants did initial error checking. Pilot participants provided extensive feedback, including identifying which areas were unclear.	Pilot participants shaped final instructions; HOMEs team incorporated their feedback	Final set of step-by-step instructions.
Evaluate online tool	Online tool was designed to automatically count fibres, allowing participants to explore their samples.	Pre-pilot and pilot participants.	Pilot participants evaluated online tool; HOMEs team incorporated their feedback	Final version of online tool.

extensive community links in their respective cities, they advised on suitable networks and shared adverts through their social media channels. The main phase was re-advertising to the pilot participants. The pilot phase required quite a high level of commitment for a citizen science project, so during recruitment effort was made to ensure that participants understood the time commitment before participating. This likely had the effect of excluding people with a lower level of engagement, but it was made clear that they could participate in the main phase if they were interested but not keen on the high level of engagement or had less time available. The only exclusion criteria were age (over 18) due to ethical restrictions. Recruitment of underrepresented groups was specifically sought via BGCP networks and community leafletting in areas considered deprived in Bristol (e.g. Lockleaze).

2.8 ▪ *Project uptake*

Five people took part in the pre-pilot. In the pilot, 29 participants returned samples and in the main phase 54 returned samples. The barriers to maintaining engagement were very different between the pilot and main phases due to the difference in engagement required. Common themes were that working with the microscopes was too complex/too technically challenging, in the pilot a few people commented that they did not like having to download an app to use one of the microscopes. The time commitment of the pilot was high for a citizen science project, which was challenging for some participants (a few noted that juggling the project with work/family commitments was challenging).

2.9 ▪ *Interviews with the HOMEs team*

One of the aims of HOMEs was to understand the challenges researchers face when using co-creation in citizen science projects. Interviews are judged in the literature to be a useful evaluation method as they directly access the observations, insights and the experiences of the participants [Tong et al., 2007]. The interviews were designed as semi-structured, and the schedule included open-ended questions, allowing participants to provide answers in their own terms [Groves et al., 2004]. Interviews took place with members of the research team at two points in time: before the pilot and again towards the end of the project. These occur either face-to-face or via email (depending on their preference and availability) and aimed to explore expectations, understand what worked well, what did not work so well, and any challenges and barriers. All members of the team ($N = 8$) were invited to take part in the interviews, eight completed the initial interview. and five took part in the final interview. This paper draws on these interviews and other reflections by the team.

3 ▪ Reflections and lessons learnt

In the pilot, participants were asked to place two dishes per room in four rooms of the house, the choice of room was left open to the participant to get an understanding of the rooms of most interest. As one would expect, commonly sampled rooms included kitchen, bedroom, bathroom and living room. Other less common rooms were hallways, studies and dining rooms. In the main phase participants were asked to monitor in the bedroom only. The decision was guided by the preferences of pilot participants and the fact that it is a room everyone has, and it is important for health (as people spend lots of time there). In future studies it would be worth considering asking participants to take photographs of the placement in the room and also of the room itself, as some were hard to interpret (e.g. a dining room may be within a kitchen, or a study could also be a bedroom). Data from the samples will be the subject of a separate paper, but initial findings from the pilot show that the microfiber deposition rate ranges from approximately 550 to 4,500 fibres m^{-2} day^{-1}. There are relatively few studies to compare these values to, but Soltani et al. [2021] used a citizen science approach to measure for a month in 32 homes in Sydney (Australia), they report a range of deposition rates from 308 to 17,642 fibres m^{-2} day^{-1}. The rate measures in this study are within, but towards the lower end of this range, which gives confidence in this simple collection method.

Further to the shared experience of developing and applying novel microplastics research with participants, the method employed appears to bear similar results and outcomes to other research projects within the microplastics and microfibre research landscape. For example, a range of previous studies had identified microfibre concentrations ranging from 308 to 17,642 microfibres [Dris et al., 2017; Soltani et al., 2021] or microparticles [Jenner et al., 2021] being deposited per metre squared per day (mf/m^2/day), whilst the HOMEs project's microfibre counts ranged indicatively from 714 to 10,000 mf/m^2/day, demonstrating the value of the method through both the participatory, knowledge creation and exchange lens and the indoor air pollution characterisation lens. This also adds weight to Aceves-Bueno et al. [2017] who determined that 50–60% of citizen science studies provide research grade data (defined as citizen science data that is considered suitable for research purposes, largely within the physical sciences [Aceves-Bueno et al., 2017]).

HOMEs was designed during the height of the pandemic and plans were made based on the assumption that the research team would not have access to people's homes, as well as how time consuming and intrusive accessing people's homes is. The pandemic was not the only reason, as going into people's homes is time consuming and intrusive, creating additional barriers sampling airborne microplastics in homes. By the time the main phase was active, the restrictions on interactions introduced by the pandemic were lifted. The research team let go of the power that researchers traditionally have over data collection by not interfering with it and that power was transferred to the participants. The team believes this helped the co-creating element of the project. Additionally, it meant a more inclusive approach as participants did not need to worry about having strangers in their homes or needing to clean and tidy due to scheduled visits by researchers.

A lot of the value of participatory citizen science projects is to allow people to access the research process, which aids in understanding how the research works [Bonney et al., 2016; Pollock & Whitelaw, 2005]. In HOMEs, participants had access to specific parts of the research process, namely the method development and data collection, and the opportunity to have a closer look at the processes and decisions within a research project. For example, pilot participants ranked microscopes in order of preference, but the final decision on which microscope to use in the main phase had to take into account the collective ranking of all participants, not individual ones, as there was not one microscope that all participants ranked as their favourite. In other situations, one particular piece of equipment might be ranked as "the best", but budget may not allow for that kit to be deployed more widely to a larger audience.

The development of mutual trust, and respect between researchers and the public is another benefit of citizen science [Walker et al., 2021; Lubchenco, 2017]. In addition, there is an associated element of humanising researchers and making them real when taking part in participatory research projects. Through our experience in WeCount, we learnt how to build trust [Sardo et al., 2021]; as a result, in HOMEs the kit was dropped off in person, which also created an opportunity to answer questions from participants, helping build confidence and increasing clarity. When recruiting participants in HOMEs, we found that certain communities do not trust researchers [Sardo, 2023], which poses a barrier to engagement. We therefore assume that HOMEs citizen scientists had a level of trust in research/researchers, which led to participation in the project. Interestingly, in HOMEs the most popular motivation to take part was contributing to research, as stated by the participants; this is in line with other citizen science projects [Fogg-Rogers et al., 2024; Sardo et al., 2022]. Contributing to research was also the favourite aspect of being involved. HOMEs had the ambition of working with a diverse audience. Numerous steps were taking to reach this aim: working with an external partner (BGCP) with connections to low-socio economic communities, BGCP then promoting the project at meetings, events and social media to groups including Refugee Integration Service Provider and the Bristol Disability and Equality Forum. Despite all these efforts, HOMEs citizen scientists were mostly white, highly educated women [Sardo, 2023]. However, having a high number of women is a positive outcome, as the participation in citizen science projects, with the exception of those focused on nature sensing, tends to be predominantly male-dominated [Strasser et al., 2023]. A successful outcome of HOMEs was that some participants took part as a family, rather than an individual. The evaluation of HOMEs revealed that numerous participants engaged their children in activities such as sampling, room selection, and particle counting [Sardo, 2023]. While demographic information about the children was not collected, the active participation of youngsters in the project was seen as positive outcome by the HOMEs team.

4 ▪ Lessons learned

Using participatory and co-creation approaches can foster active participation and meaningful engagement from participants. Highly engaged participants were involved during the pilot phase, requiring deeper engagement and a greater time commitment, both from the participants themselves and from the HOMEs team. In contrast, the main phase involved participants who were less engaged, with shorter periods of involvement and a reduced time commitment.

Based on our experience with the microscope selection process, it is evident that the design of citizen science projects should prioritize high levels of participant engagement and satisfaction, at least during certain stages of the project. However, this focus on engagement does not always align with the optimal scientific approach and requires a compromise between the goals of researchers and the needs of participants. Although most participatory citizen science projects are conducted asynchronously, some face-to-face interactions, such as delivering kits in person, can add significant value.

Finally, the choice of topic may determine the easiness of engagement and participation. The team found it easy to engage participants with the topic of microplastics, as many expressed that this issue is increasingly recognized as important.

5 ▪ Future strategies

Despite our efforts, the project struggled to recruit participants from a diverse demographic. This highlights a key lesson in citizen science: while outreach efforts can extend to a wide audience, participation ultimately remains voluntary. To address this challenge, future projects might benefit from developing deeper, more embedded relationships with the community. Although this approach is difficult to scale, it could be tested in specific contexts to assess its effectiveness.

The project's short duration limited the ability to build meaningful relationships with participants, though such relationships may not be necessary for every co-creative project. The challenge was exacerbated by the project's design, which anticipated limited interactions with participants due to potential pandemic-related restrictions. We recommend planning longer co-creative projects to allow more time for relationship-building.

In terms of communication, the project primarily relied on X/Twitter, which proved too passive for effective engagement. Future projects should establish a comprehensive communication plan from the outset, ensuring more proactive and varied methods of reaching participants and maintaining engagement.

Additionally, several challenges, such as the need for a pre-pilot phase, only became apparent once the project was already underway. This added to the workload and delayed the progression of other phases. These issues can often be identified earlier with more team's experience in citizen science and co-creative projects. To support this, future funding calls could benefit from greater flexibility, allowing research teams to explore and adapt their approaches more fluidly, which could help in identifying potential issues earlier in the project lifecycle.

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