Research Topics

# Bridging citizen science and science communication

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# Bridging citizen science and science communication

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# Editorial: Bridging citizen science and science communication

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Editorial on the Research Topic
Bridging citizen science and science communication

## Introduction

The growth of public engagement in science is supported by two complementary fields of research and practice: citizen science and science communication. Presenting unique opportunities for the development of science in society, the two fields serve as agents of change. Both independently and in tandem, science communication and citizen science catalyze scientific innovations, raise environmental awareness, drive informed resource management, and promote sustainable development.

Science communication is the practice of making science accessible, understandable and engaging, for diverse audiences (Fischhoff, 2013). Participatory approaches emphasize the importance of two-way dialogue between scientists and the public, allowing for mutual benefit through active listening and shared learning (Brossard and Lewenstein, 2009; Bucchi and Trench, 2014). Citizen science, sometimes termed participatory or community science, is an umbrella term that describes the variety of ways in which the public can, and is participating in science. Citizens may act as contributors, collaborators, or as co-creators of scientific research projects, thereby fostering a more inclusive and participatory approach to scientific inquiry (Hacklay, 2013). Through their active involvement, citizens contribute with diverse perspectives, local knowledge, and valuable data, enriching scientific research and its applications. Though established independently, citizen science and science communication have multiple overlapping and interconnected aims in common. Research and practice in both fields is moving in a direction that favors an increased focus on participatory methods of dissemination and collaboration that move beyond top-down and one-to-many approaches and seek community involvement at each stage of the research and practice processes. Similarly, both fields are grappling with challenges concerning equity, diversity and inclusion (Giardullo et al., 2023).

In their editorial of the "Participatory science communication for transformation" Research Topic, Metcalfe et al. (2022) ask the question: "*is citizen science the same as participatory science communication*?" Defining participatory science communication as a

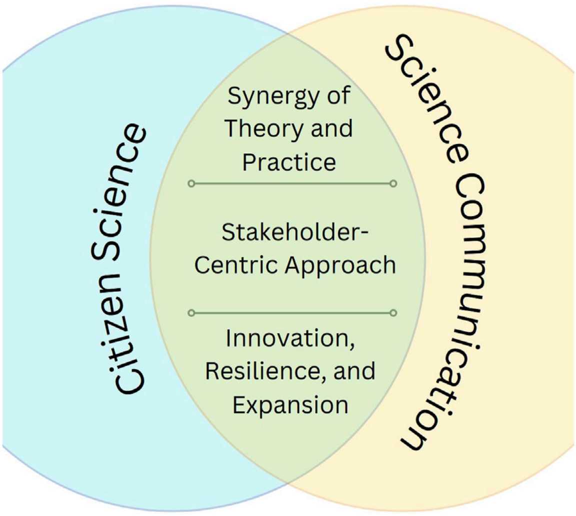


FIGURE 1
Three key themes considered in this Research Topic.

practice recognizing publics as equals in terms of the power and knowledge they hold, they explain that while these are distinct practices, more extended forms of citizen science can reach the "participatory level of science communication." The diversity of citizen science projects can be placed on a continuum based on the power that citizens hold within a citizen science project (Gascoigne et al., 2022) matched to varying levels of science communication. For instance, contributory projects, where participants engage in simple data collection tasks, may align with the deficit model, while co-created projects, involving the public in all research stages, tend to align more closely with the participation model (Sagy et al., 2019; Gunnell et al., 2021). The NEWSERA project, for example, demonstrated that citizen science projects often interpret communication as a dissemination activity without harnessing its potential for deeper engagement of multiple stakeholders (Magalhães et al., 2022; Giardullo, 2023). However, this is not always the case, as demonstrated by Golumbic et al. (2020) a spectrum of science communication practices can co-exist within one citizen science project, from a deficit style of data presentation to its dialogic design ensuring accessibility and transparency.

## Research topic overview

This Research Topic explores the reciprocal relationship between citizen science and science communication, investigating a wide range of communication strategies employed in citizen science. Contributions include original research, case studies and theoretical perspectives that discuss Research Topic including interactions within and between citizen science quadruple-helix stakeholders (civil society, scientific community, policymakers, industry) (Carayannis and Campbell, 2010), interaction with media outlets, attracting and retaining participants, communication life cycles and inclusionary practices.

The contributions to this Research Topic have been considered along three key themes that capture the interplay between theory and practice, the importance of stakeholders, and the innovative aspects and expansion of both citizen science and science communication (see Figure 1).

### Synergy of theory and practice

The first theme, highlighted by four papers, explores the synergy of theory and practice at the intersection of citizen science and science communication. Raetzsch et al. focused on two citizen science subgroups; civic tech and citizen sensing, emphasizing their deliberate activist nature and underscoring the importance of co-creation for effective communication among stakeholders. This aligns with a fundamental science communication principle - identifying the audience and tailoring the message in a way that relates to their needs and interests. Within a particular project, with varied stakeholders and audiences, negotiation is required in order to find the right balance to communicate effectively. Golumbic and Oesterhelds investigation into citizen science project descriptions echoes the challenge of aligning communication with its audience, in this case the broader public and potential participants of citizen science. The authors found that project descriptions often mimic scientific abstracts, are inconsistent with science communication best practices and commonly neglect practical and community-related aspects. Exploring the utility of science communication models within citizen science projects, Lorke et al. applied the science communication rosette model to citizen science bioblitz activities. They demonstrate a nuanced pathway from activities initially aligned to the deficit model to their practical application within the dialogue, and participation models, emphasizing the visual clarity offered by the rosette model in identifying programming gaps and optimizing participant engagement. Finally, Roche et al. add a practical dimension to theoretical discussions about the interconnectedness of citizen science and science communication. Their survey investigating the identities and roles of science communicators reveals an interesting overlap, with 11% of science communicator respondents identifying as citizen scientists. Collectively, these papers offer an exploration of theoretical underpinnings, the application of science communication practices within citizen science, insights from professionals engaged in both realms, and the advancement of interdisciplinary research agendas for citizen science.

### Stakeholder-centric approach

The second theme focused on key aspects for developing stakeholder-centric approaches. Eight papers addressed this theme, identifying how communication strategies are used across the full life cycle of citizen science projects (i.e., recruitment, coordination, data collection, validation, and dissemination), how they can be tailored to specific audiences, and how to make them more inclusive. Dittmann et al. examine the key role of communication strategies in the success of Plastic Pirates, a project that engaged schoolchildren in collecting data on riverbank litter pollution across the European Union. They particularly highlight the challenge of time constraints and recommend regular communication, diverse channels, and feedback mechanisms to enhance efficiency for broader stakeholder engagement. A similar programme in Latin America (Thiel et al.), Científicos de la Basura (Litter Scientists), engaged teachers and schoolchildren in monitoring anthropogenic litter and highlighted co-creation, remote training, support, and guidance to mitigate challenges such as team capacity and socio-economic stability. Furthermore, Schumann et al. present a community case on urban wildlife monitoring, demonstrating the benefit of intentional recruitment strategy design and underlining the importance of tailored communication approaches for effective project outcomes. To complement previous approaches, Kapono et al. advocate for the integration of branding and marketing techniques as powerful support for science communication in citizen science projects. Using the example of the Multiscale Environmental Graphical Analysis (MEGA) lab in Hawaii, the authors show how elements such as storytelling, inclusivity, and personalisation boost visibility, credibility and increase the potential for wider audience reach. Moving forward into inclusion aspects and art-based methods for engagement, Veeckman et al. explored a storytelling-based framework to address inequality and foster inclusivity of vulnerable youth groups for social justice around specific Research Topic, such as climate. The STORCIT ("Storytelling in Citizen Science") framework, tested with young people in Belgium, supports participants to reflect on their stories, amplify their voices, and catalyze actions. Iwanycki-Ahlstrand and Tøttrupv, examine the lack of demographic diversity in citizen science participation in Denmark through the "Our Nature" campaign. The authors demonstrate the value of building cross-sectoral partnerships and adopting inclusive practices and their impact on project success and public engagement beyond traditional participants. Through "project M," Murray et al. formed "actual bonds" between both molecules and communities, improving the quality of engagement opportunities of UK secondary students by facilitating meaningful discussions and collaborations with scientists, on a very specific Research Topic; the synthesis of calcium carbonate. Finally, Roche et al. interrogate the discussions of inclusivity at major citizen science, science communication, and public engagement conferences held in 2023. The authors critically analyze the need for equity, intersectionality, and constant reflexivity within the academic and professional communities at conferences. They call for the prioritization of inclusion and for the embedding of diversity considerations in all stages of conference development.

## Innovation, resilience, and expansion

The third theme, highlighted by three papers, explores three distinct yet interrelated themes of innovation, resilience and expansion in citizen science approaches reliant on applying and/or interrogating best practices in science communication. Roger and Kinsela presented case studies of co-designed citizen science projects, in response to the impact of catastrophic bushfires in Australia in 2019–20. Key to the success were promotional strategies that empowered different groups of citizen scientists. At a time when the community was in shock, citizen science built connections between research teams, government and the broader community, fostering a shared sense of resilience. Raetzsch et al. which was also discussed under the "Synergy of Theory and Practice" theme, raises the potential for the expansion of citizen science into civic tech and citizen sensing programs. The authors discuss the opportunities and tensions of participatory journalism and suggest integrating clear and inclusive communication with ethically obtained crowdsourced data to rebuild trust between the public and the media. Wilkinson et al. perspective article challenges us to consider a potential role for citizen science in death and dying research or end of life care. At this moment in history (following the COVID-19 pandemic) where conversations about death and dying have played out more openly in the media, the authors position citizen science as a possible methodology to encourage two-way conversations between researchers and the public around this challenging and sometimes taboo Research Topic.

## Summary

When this Research Topic was first envisioned, the co-editors shared many intentions; advancing the relation between citizen science and science communication, placing a spotlight on research-practice collaborations, encouraging citizens to serve as co-authors and/or be otherwise acknowledged, and sharing a widespread geographical representation of examples. While making progress towards these goals, a wealth of other insights emerged along the way. Synergies between citizen science and science communication theory and practice were revealed, but also gaps in its implementation. While diverse communication strategies have shown to be implemented throughout a citizen science project's lifespan, challenges in time and resources were evident. Finally, while the richness in Research Topic, locales and innovative methods advancing the field are clear, there is also much untapped potential to further progress the field in unexplored areas.

Contributions to this Research Topic span examples from Asia, Australasia, Europe, North America and South America. They also represent projects from fields of environmental science, chemistry, biodiversity, climate and social sciences. Interestingly, the majority of articles represent case studies discussing practical applications of science communication, or perspectives discussing the importance of integrating practices and future directions. This provides an important platform for community-based projects to contribute their perspectives and insights to strengthening advances in the field and for the citizen science community to learn from practical, successful experiences. However, amid this inclusivity, questions arise regarding the research practices guiding such endeavors. Considering the importance of anchoring practice on research and theory, how can the standards of research be ensured while also welcoming diverse voices? These include accounts of practice from project leaders, non-traditional research outputs and perhaps most importantly voices of those participating and contributing to projects.

One potential solution to address this challenge is to establish an alternative publishing platform, such as the library of resources envisioned for the future virtual platform of the European Competence Centre for Science Communication (Magalhães, 2023), following certain quality criteria (ensuring, for example, science communication, scientific, accessibility and ethical principles) or standardizing the way to report initiatives (e.g., as offered by the Stardit framework (Nunn et al., 2019)). This may also address challenges related to time constraints, limited funding, and barriers associated with traditional peer-reviewed publications, particularly for individuals not affiliated with academic institutions.

To summarize, the integration of citizen science and science communication presents rich opportunities for interdisciplinary collaboration and progress. Despite diverse strategies and exploration, challenges in resource allocation and ensuring research standards persist, underscoring the need for further advancement in uncharted territories and addressing challenges of time, funding, and inclusivity.

## Author contributions

YG: Conceptualization, Visualization, Writing–original draft, Writing–review and editing. JM: Conceptualization, Writing–review and editing. AM: Conceptualization, Writing–review and editing. JR: Conceptualization, Writing–review and editing.

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## Conflict of interest

JM is hired by Science for Change.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# Science communication is integral to attracting widespread participation in bushfire recovery citizen science

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The 2019/20 bushfire season was a catastrophic event affecting large areas of Australia. Due to the devastating impact on biodiversity, the Australian public wanted to contribute towards assessing the impact of this disaster. To address this, three citizen science projects were established to engage citizen scientists in various aspects of environmental recovery. The projects offered different ways of participating, ranging from online, through to community field events, including those requiring specialised localised knowledge. As a result, communication approaches targeting different audiences were required. Here, we detail the communication strategies employed to promote and engage a diverse national and global audience in bushfire recovery projects. We provide metrics and analysis on how and where we promoted projects, including a breakdown of participation numbers for each project. We detail lessons learnt, and how we would improve our communication approach for future disaster recovery events to increase awareness at a community level and more broadly. Despite numerous challenges, including organising public-facing events during a global pandemic, the program serves as an exemplar of how to successfully partner with communities, research teams and government to enable citizen scientists to make meaningful, valuable and timely contributions to research. Ultimately, the program enabled widespread community involvement in bushfire recovery and filled gaps in baseline and post-fire data.

KEYWORDS

**citizen science, communities, disaster & climate risk reduction, bushfire recovery, co-production**

## Introduction

The 2019/20 bushfire season was a catastrophic event affecting large areas of Australia, with a total area of between 7–10 million ha of the national landscape burned (Gallagher et al., 2021; Auld et al., 2022). Some areas throughout the south-east were particularly impacted, such as South Australia's Kangaroo Island where almost half the island burned (Bonney et al., 2020). Fires of the magnitude experienced during this spring and summer period were unprecedented for present-day climatic conditions (Nolan et al., 2020), with the impact on biodiversity widespread and well documented (Ward et al., 2020; Dickman, 2021). The fires had a huge emotional impact on people both within Australia (Filkov et al., 2020) and globally, eliciting strong responses from communities wanting to help and contribute to recovery where possible. Citizen science for disaster risk reduction and recovery holds huge potential and has already demonstrated success in advancing knowledge, providing early warning and contributing to post-disaster monitoring and management (Hicks et al., 2019).

Citizen science targeted at bushfire monitoring is one mechanism to engage communities directly in both the science (Rowley et al., 2020; Kirchhoff et al., 2021) and also to build community resilience (Chari et al., 2019). It presents opportunities to engage in the science of recovery *via* a number of mechanisms, but is most widely applied in collecting postfire data (Kirchhoff et al., 2021). Scientific benefits of engaging in citizen science include the ability to collect post-fire data across areas typically inaccessible to professional scientists (i.e., private land) and the ability to collect data at large temporal and spatial scales (Chandler et al., 2017; Roger and Motion, 2022). This can be particularly relevant when travel or site access is limited due to hazardous conditions or restricted travel conditions (i.e., COVID-19 pandemic). With federal and state-based recovery actions being prioritised and monitoring programs developed across bushfire regions, an opportunity arose to build a program that engaged citizen scientists in the environmental monitoring of recovery and aligned with government priorities. As a result, three citizen science projects were co-designed with government to engage communities in various aspects of environmental recovery and help fill identified knowledge gaps.

## Bushfire citizen science program

The program of work was a collaboration between the Australian Commonwealth Government Department of Climate Change, Energy, the Environment and Water (formerly the Department of Agriculture, Water and Environment) and the Atlas of Living Australia which is hosted by CSIRO. The Atlas of Living Australia (ALA) administered the program and partnered internally with CSIRO's National Research Collections Australia and externally with the University of New South Wales and Western Sydney University to run the three targeted projects.

### Project 1: Big Bushfire BioBlitz

The purpose of the bioblitzes was to generate new evidence on the impacts of large-scale fire on biodiversity, and to support fire-affected communities to re-engage with nature and the science of recovery (Weill et al., 2020). The events took place over a 46-h period in spatially-adjacent burnt and unburnt areas in: The Greater Blue Mountains World Heritage Area (25–27 February 2022); forests of the NSW south coast (Murramarang National Park, 11–13 March 2022); and rainforests of the NSW North Coast and tablelands (6–8 May 2022). Locations were chosen based on accessibility, the support of park rangers and local area knowledge of trails and conditions. For bushfire impacted communities outside of the three locations listed above, the Big Bushfire BioBlitz project on the iNaturalist biodiversity platform was open to receive observations from citizen scientists from across Australia for the duration of the event series. Local and external experts, including researchers from the Centre for Ecosystem Sciences at UNSW, were invited to participate and provide their expertise at specific events. During each bioblitz, a number of structured surveys were conducted at planned times and at predetermined locations with each survey led by an expert or researcher and conducted with citizen participants. Participants were able to be autonomous and make observations independently of any planned surveys or expert-led walks and events, and at their own pace. All aspects of biodiversity (flora, fungi, fauna) were recorded, with all observations generated from the Big Bushfire BioBlitz open source and aggregated in the ALA biodiversity infrastructure from observations submitted to the iNaturalist, FrogID, and eBird biodiversity platforms.

### Project 2: Flora connections

Flora Connections was designed to encourage flora groups to record post-fire recovery of priority plant species. The concept of this project was to draw on the expertise of active amateur botanists who have a strong connection to the plants in their local area to monitor and document priority plant species using a standardised method of recording how Australia's unique plants recover from fire. The project developed resources to help local flora groups record priority plant species observations using systematic data collection methods. A standardised method ensures decision-makers are confident to use the data in their assessments of bushfire impacts on flora (Boho et al., 2020). The first step involved creating an inventory of active flora groups throughout Australia. A survey data sheet was developed to include important information such as site and habitat information, species description, population numbers as well as disturbance and threats. A step-by-step guide was then prepared to help direct identified active flora groups through the established monitoring protocol. The guide explains the concept and aims of the project, how to record information and where to upload it. A website floraconnections. com was also developed as a resource for additional information and as a portal to submit data which is all open source on the Atlas of Living Australia. The website includes information on priority plants to help guide users in selecting which plant species to monitor. Priority plant species were selected based on a list of species (provided by the Commonwealth Government) that require assessment for 'threatened' status. Information on any of these plants may help secure funding for their future management and conservation (Auld et al., 2022). A survey 'light' version was created on the iNaturalist platform to encourage additional observations from people who were not able to commit to a systematic survey described in the methodology.

### Project 3: Invertebrate digitisation

The Invertebrate Digitisation Project involved prioritising insect digitisation based on a list of priority invertebrate species requiring urgent management intervention or on-ground assessment, and was initiated post-bushfire by the federal Department of Climate Change, Energy, the Environment and Water (Department of Climate Change, Energy, the Environment and Water, 2021). This project was developed on the basis that there are over 8,000 specimens in CSIRO's National Research Collections Australia that are on the provisional list of priority invertebrate species. As such, the collection was identified as an invaluable resource in helping to inform their assessment. The goal of the project was to create a digitised and accessible historic insect data set that could help decision-makers prioritise invertebrate species for present day monitoring and intervention programs. Citizen scientists were engaged in the transcription of specimen labels using the online DigiVol (https://digivol.ala.org.au/) platform run by the Australian Museum. Images were loaded onto the platform in batches of around 800 with each batch called an “expedition”. Once transcribed and validated, the information was then loaded into the ALA, providing a permanent historical record of the occurrence of a species at a particular time and place.

## Science communication

Science communication is increasingly being used as an integral tool with citizen science (Roger and Klistorner, 2016), and is crucial for promoting projects to engage participants, communicating results and project outcomes throughout the research process (Wagenknecht et al., 2021). Using science communication and citizen science as complementary approaches can help participants gain a shared understanding of the research process (Fischhoff, 2013). This becomes more crucial when participants in bushfire citizen science projects likely have a deeply rooted investment in understanding environmental recovery in their local area and how the science is being used to help inform management and policy decisions. Indeed, science communication is critical for highlighting community interest in contributing and participating post disaster event. Importantly, when science communication is performed well, it facilitates a two-way exchange of information, or knowledge co-production (Norström et al., 2020). Citizen science provides the mechanism to share this knowledge (Wagenknecht et al., 2021). Finally, a challenge for many citizen science projects is attracting participants and maintaining motivation throughout the life of a project. Therefore, science communication has an important role to play in the success of citizen science.

Here, we aim to demonstrate how we used best practice science communication to attract participants and promote the wider bushfire citizen science program more broadly. We provide metrics and analysis on how and where we promoted projects, including a breakdown of participation numbers for each project. We detail lessons learnt, and how we would improve our communication approach for future events to increase awareness at a community level and beyond. Our objective is to showcase how the reciprocal arrangement between citizen science and science communication can result in an exemplar of how to successfully partner with communities, research teams and government to enable meaningful and timely contributions to bushfire research.

# Detail

The audience for this program was the Australian community as it was designed to respond to community interest and harness the power of citizen science for understanding bushfire recovery. To try and ensure inclusive engagement with the Australian public we adopted several whole-of-program tactics. The Federal Government partner launched the program with a Ministerial media release, which was amplified *via* CSIRO’s media and social media channels. The launch was also supported with a promotional newsletter which was distributed to over 89,000 people (average open rate of 31%, 7.2% click through rate), and accompanied online blogs for both ALA and CSIRO channels describing the project (Figure 1). All three projects were listed on the Australian Citizen Science Association’s Citizen Science Project Finder (ACSA, 2023) to increase discoverability.

Each project was promoted separately, depending on when individual projects were due to start, using a mix of communication platforms, e.g., radio, television news, media releases, blogs, newsletters, and social media (Figure 1). The communication tactics used were dependent on the project. For the bioblitzes, the widespread media campaign focused on eastern Australia due to the locations of the surveys (Figure 2). Events were promoted with a link to the registration page using local radio, and an ALA newsletter item. The University of New South Wales partner issued their own media release that was sent directly to media outlets servicing communities within geographical proximity of the events, resulting in 14 separate re-postings across online news sources. Organisers also spoke on local radio, again targeting areas impacted by the fires and in close temporal proximity to events. The events were also promoted on the ALA’s Twitter account. During one of the bioblitz events, a survey with Gardening Australia’s Costa Georgiadis (an Australian television personality) was livestreamed (Facebook). This engaged a broader cohort in the initiative and increased accessibility to the events for those unable to participate in person and attracted a wide audience on the social media platform Facebook (Figure 1). During the bioblitzes, community-level expertise was sought, as many participants were local and shared insights and knowledge about what they were observing on the day. As such, local knowledge was used to help inform identifications of the biodiversity recorded (Danielsen et al., 2018).

The Flora Connections Project was the most widely publicised project in terms of reach (Figure 1). CSIRO issued a media release when the project opened for participation, and further promoted through local radio and television, as well as sharing across CSIRO and ALA Twitter, Facebook and Instagram accounts (Figure 1). All media and social media directed towards the flora connections website where people could learn more about the project and submit data. Physical manuals were also mailed to various plant societies to encourage participation in the project and follow-up emails to all flora groups were sent.

The Insect Digitisation Project was promoted on a CSIRO blog and through ALA Twitter and Facebook postings. A blog was chosen as the preferred information dissemination pathway as it enabled direct linkages to the online project from the webpage and suited the broad (Australia-wide) audience targeted for this project. Findings and outcomes of all projects were reported directly *via* email to bioblitz participants and indirectly using online platforms, such as social posts and a webpage with a summary of project findings. It was also ensured that all data remained publicly available for all three projects *via* the ALA.

# Results

## Big Bushfire BioBlitzes

Over the three separate, 3-day-long events: 7,956 observations of species were made, representing 1,773 unique species. More than

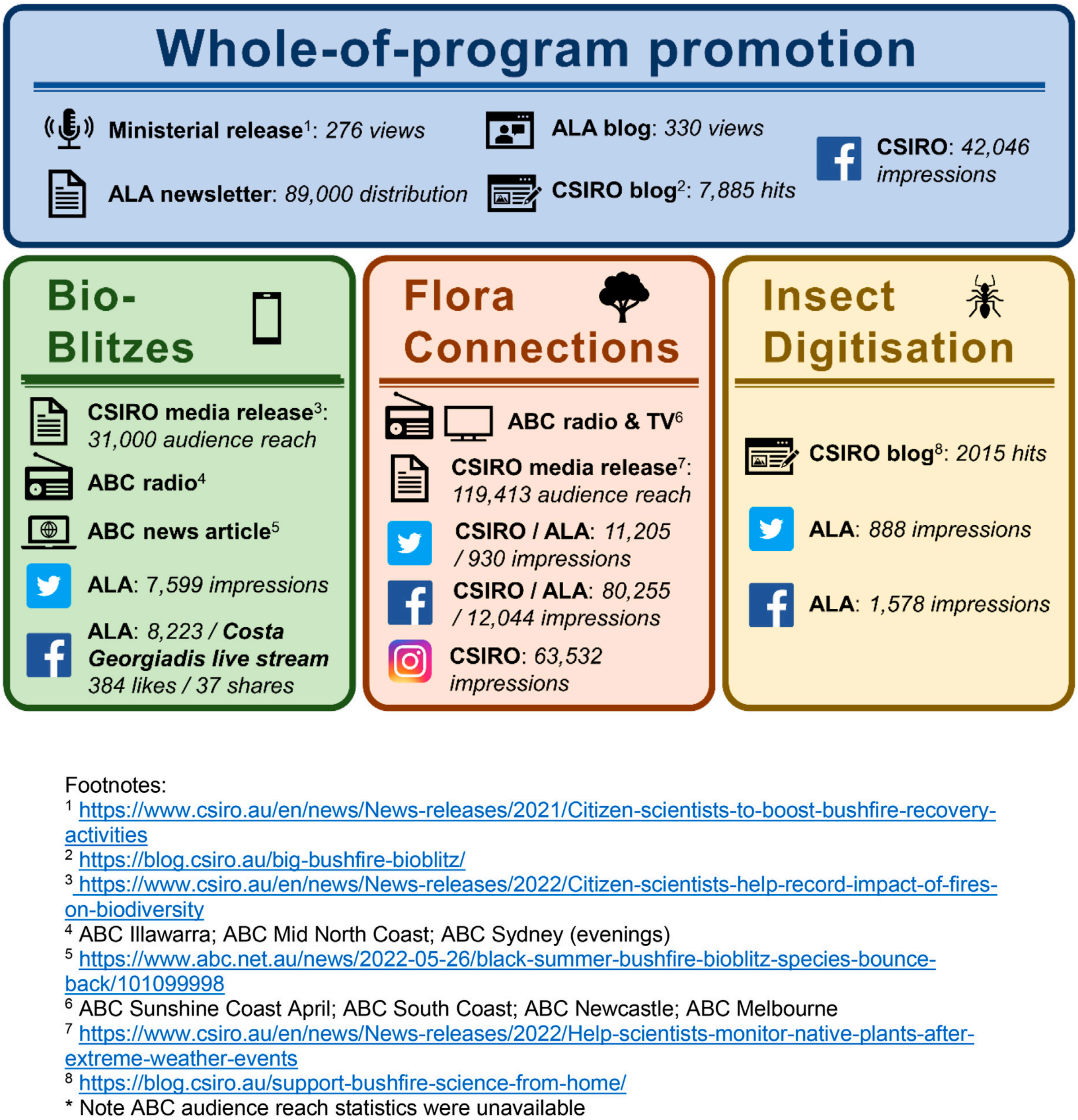


FIGURE 1
Summary of the communication outreach and platforms used to promote the citizen science bushfire program.

535 people participated *via* both in-person and through online identification (Figure 2). There were over 200 event registrations for the first two events and 35 online registrations for the third event. Participants were not explicitly surveyed for demographic and background information, anecdotally it was found that the events attracted scientists, community amateur experts, government officials and interested members of the public across a wide range of ages.

## Flora Connections

Twenty-seven complete surveys of nine different priority plant species have been completed for the Flora connections project at the time of writing. For the iNaturalist light-version, four people have participated, collectively contributing 18 observations of seven priority plant species. This project is still open for participation. Although participants were not explicitly surveyed for demographic and background information, anecdotally this project has attracted an even representation of genders with participants typically aged between 20–50 years.

## Insect digitisation

Over the course of the project, more than 8,000 specimen images were digitised and loaded onto the ALA for specimen

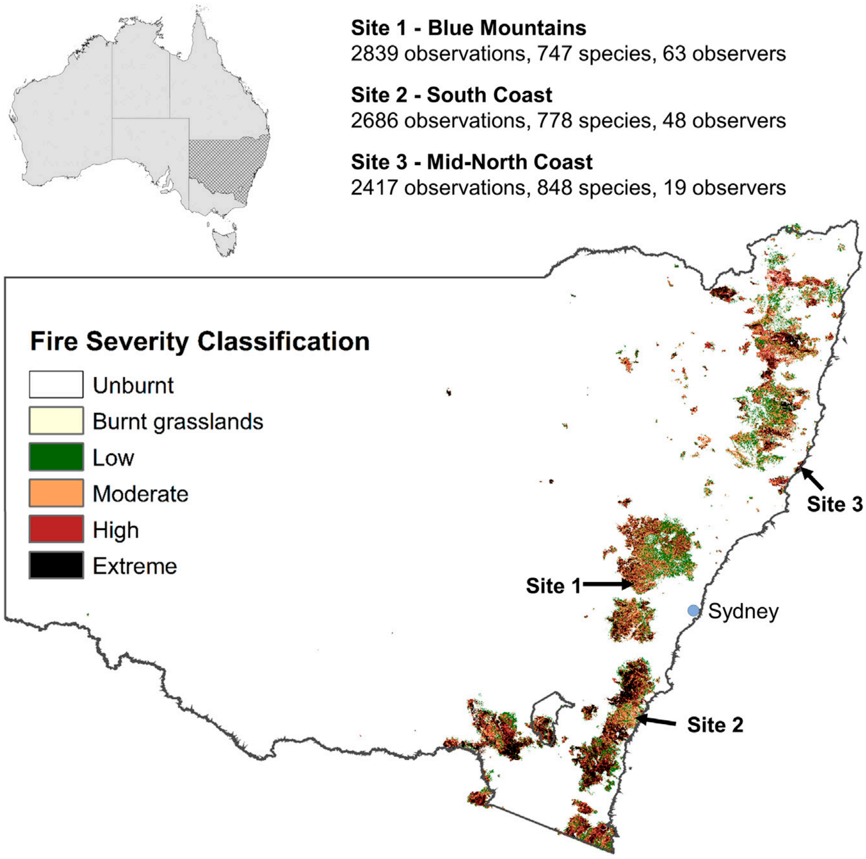


FIGURE 2
Big Bushfire BioBlitz locations overlayed against the 2019-2020 bushfire impact areas in NSW Australia. Total number of species observations, species and observers are provided for each bioblitz. Base maps were made using ArcGIS Desktop 10.7.1. The fire map layer was made using "Fire Extent and Severity Mapping (FESM) 2019/20" ESRI file, available from the NSW Department of Planning and Environment—SEED The Central Resource for Sharing and Enabling Environmental Data in NSW.

label transcription (Figure 3). Although eastern Australia was not targeted for this work, given that it was online and open to anyone, the majority of online participants were from the eastern states and territories of Australia (Figure 3). A total of 258 citizen scientists participated in the online label transcription, with 27 serving to help validate and check the metadata from this work. We do not have project specific participant information, however, a report prepared for the DigiVol platform found that the majority of volunteers on the site were female (70%), the youngest participant was 12 years of age and the oldest 90, with the majority (43%) aged between 61 and 75 years (Haski-Leventhal and Alony, 2021). Many participants were motivated to join DigiVol because of the online convenience and flexibility online volunteering affords (Haski-Leventhal and Alony, 2021).

## Discussion

Citizen science and science communication have complementary roles in bushfire recovery citizen science to engage stakeholders and participants, engender a two-way flow of information and disseminate findings to demonstrate impact. We argue that in the context of disaster recovery, dependencies between science communication and citizen science are critically important, particularly amongst communities physically and or emotionally impacted by disaster events. Through these projects, a connection between science and knowledge, government policy and initiatives, and public expectations and desire to contribute to recovery efforts after major natural disasters can be provided. It is generally acknowledged that the greater the increase in public participation in research, the greater potential there is to build trust in both the organisations involved and the science undertaken (Christopher et al., 2008). Both citizen science and science communication have integral roles in engendering trust in the science of disaster recovery by actively seeking to partner with communities in science. Science communication is central; needed to publicise events and enable the recruitment of participants at appropriate project scales and timelines. One of the many benefits of citizen science is the capacity for relatively rapid responses across vast spatial scales (Gibson et al., 2021), making science communication critical for communicating the opportunity to communities (Hecker, 2022).

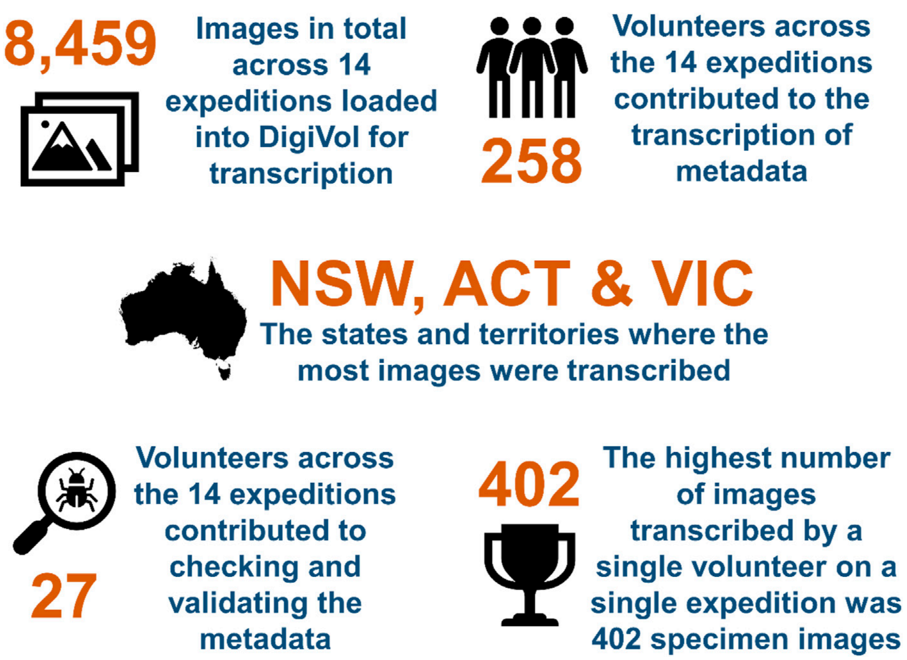


FIGURE 3
Insect digitisation project statistics on the DigiVol platform where volunteers transcribed specimen labels.

Communicating the impact of the science undertaken with participants is also critical and provides an understanding of the role of fire in landscapes and perceptions of recovery (Weill et al., 2020).

Promoting the whole program of work as well as the opportunities to participate were critical to the program's objectives to raise awareness of the work and attract participants. To ensure inclusive participation (although this is not something we were able to exclusively test), initiatives were developed that were accessible to a wide variety of people through both online and field-based activities, thereby catering for a range of interests, time constraints, mobilities and locations (Haski-Leventhal and Alony, 2021). A combination of methods (field, scientific collections, crowdsourcing) were employed to attract a variety of interests and target species of interest and areas of concern for monitoring (Steven et al., 2019). As testament to our approach, this program of work engaged hundreds of people directly in science and thousands of people indirectly *via* media, social media and newsletters. By generating more than 14,000 open access datapoints in the ALA across the three projects we ensured that this information was available for decision-making. To achieve these results, we needed to mobilise communication resources and use a mix of media to attract widespread participation and program uptake. We built a feedback loop into program findings so that participants could understand how they contributed to a broader program of knowledge. We did this through update emails and website blogs reporting on project findings and next steps. The accessibility of collections and data was increased so that data can be used in real-time application. It also served to provide communities a window into scientific collections rarely publicly seen and scientific approaches to fill gaps to inform management and decision-making (Steven et al., 2019).

## Lessons learnt

Despite the success in attracting participants, a number of lessons became apparent from organising the three projects. Although largely out of our control, the bioblitzes were organised during the COVID-19 pandemic and had to be postponed from an ideal sampling period in spring to a summer/autumn period due to travel restrictions and limits on public gatherings. Unprecedented major flooding also occurred during our events, resulting in significantly lower turn-out than pre-registrations had indicated. For one event, flooding also forced the short-notice relocation of preferred sampling locations to a different locality and date. This resulted in a substantially smaller lead time to promote this particular event, which was reflected by the lower level of participation (Figure 2; Site 3). Crucially though, a number of interested locals who happened upon the events and were not aware the bioblitzes, were identified. Targeting local groups such as Landcare, bushwalkers and birdwatchers *via* community newsletters and meetings would appear to have been an overlooked channel of communication to promote events at the local level (Danielsen et al., 2018). Live streaming the event was also successful, suggesting this strategy should be adopted for future events to increase accessibility even further.

The Flora Connections Project received the most amount of publicity but attracted comparatively few participants. This was likely because the survey method was complex and not well suited to a general audience, in line with observations made by Hochachka et al. (2012), that uncomplicated protocols attract larger numbers of volunteers. Although various active flora groups were directly approached, this did not translate to further levels of participation. Initial volunteer involvement rates prompted the creation of the iNaturalist "light" method; however, this new method was not widely promoted as it was developed after all the project publicity was concluded. This finding suggests that detailed data collection needs tailored systematic promotion. Since these initial results, the project employed a communications officer to engage directly with groups and help teach the method. The project is now engaging directly with university course co-ordinators teaching conservation and ecology and raising awareness of Flora Connections as a teaching resource. The protocols and tools are intended to be used as part of a newly created Threatened Flora Network across Queensland which will work directly with local amateur botany groups to collect data on threatened plants across Queensland, which should translate to increased future participation in the project.

Online insect digitisation specimen label transcription was very popular on the online platform with all expeditions completed within 4 days. The level of communication to promote this project was adequate, and indeed additional tasks ready for citizen scientists to undertake at the time of publicity would have been preferred in order to meet demand. Online projects are typically very popular as they can be undertaken at any given time and locality (Aristeidou and Herodotou, 2020). Online label transcription allowed volunteers a unique glimpse into biological collections that they would otherwise not witness. For example, some of the specimens digitised for this project (and transcribed) were over 100 years old, while other specimens were the first recorded images within the ALA and the Global Biodiversity Information Facility (GBIF).

## Conclusion

The 2019/20 bushfires were a significant natural disaster which at the time of the fires, elicited a strong response from the community. This program responded to the interests of the Australian people and enabled widespread community involvement in the science of bushfire recovery. It was also designed to fill identified gaps in post-fire data and improve both community and science's understanding of environmental recovery. The program serves as an exemplar of how to successfully partner with communities, research teams and government to enable citizen scientists to make valuable and timely contributions to research. It also provides a framework that can be replicated in the event of other disaster events, thereby giving longevity to these kinds of initiatives. The success, measured by the volume of publicly accessible data generated, and the reach of the program across communities, is due to the strength of engagement with partners and citizen scientists, as well as the passion of the individuals involved in caring for their local areas. Ultimately, it was the coupling of science communication and citizen science that allowed for an enhanced public awareness of bushfire science and the contribution of communities to Australian biodiversity science.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

## Author contributions

ER conceived of the idea in discussion with AK and ER drafted the manuscript with support, input and edits from AK. AK produced all figures. All authors reviewed the manuscript and agreed to the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note

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# Mainstreaming civic tech and citizen sensing: a research agenda on co-creation methods, data interfaces, and impact pathways

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In this perspective article, we propose an interdisciplinary research agenda that addresses citizen science approaches embedded in civic tech initiatives and citizen sensing scenarios. The proposed agenda builds on the multi-level perspective framework (Geels, 2004; Geels, 2019) to inform research on how such 'niche innovations' like citizen sensing become mainstreamed in broader socio-technical systems and modes of governance. To support research across use case scenarios and make analyses more comparable internationally, we identify three core areas of interdisciplinary future research and practice development: 1) uses of co-creation methods to develop project objectives and align stakeholders; 2) designs of interfaces for gathering, communicating, and archiving civic data for different types of users; and 3) modeling impact pathways of individual projects that include civic tech activists and citizen scientists, academic researchers, journalists, and policymakers. For impact pathways, we highlight the importance of collaborations with data-driven approaches in journalism.

KEYWORDS

**civic tech, citizen sensing, citizen science, data journalism, comparative framework, data interface, civic data**

## 1 Introduction

Citizen science has been a growing global approach to include non-experts in the creation of scientific knowledge. It is employed in diverse fields covering different types of activity, e.g., as an outreach strategy of public research institutions, as a form of collective environmental monitoring [e.g., in urban spaces (Longo et al., 2020) or radioactivity after the Fukushima disaster in 2011 (Brown et al., 2016)], or by crowdsourcing labor-intensive, repetitive scientific tasks (Raddick et al., 2013). In their extensive overview of citizen science definitions, Haklay et al. (2021) mention core elements such as "the generation of scientific data," being based on "(engaging) volunteers over a large area," and "(addressing) a politically relevant issue" (Haklay et al., 2021: 14). The authors admit that there are tensions between "descriptive, instrumental, and normative elements" in many definitions (Ibid. 22), which poses "an inherent challenge in providing an exhaustive definition of citizen science" (Ibid. 14).

These tensions highlight that collaborative knowledge creation in citizen science differs from established methods of academic research and science communication. Citizen science approaches often seek to involve (and also empower) citizens in the scientific understanding of social, environmental, and political issues. In this perspective article, we propose an interdisciplinary research agenda that targets citizen science approaches employed in certain types of civic tech projects (Schrock, 2019; Harrell, 2020), and in particular, in citizen sensing projects, i.e., the crowdsourced collection of environmental data through citizens (D'Ignazio and Zuckerman, 2017; Coulson et al., 2021). Based on the established multi-level perspective framework (Geels, 2004, 2019), we consider civic tech and citizen sensing approaches as 'niche innovations' which seek to affect and change broader socio-technical regimes, e.g., science, local governance, or democratic culture.

Civic tech and citizen sensing projects show elements of citizen science, yet often are deliberately developed as activist and political interventions. They often involve the development of platforms or technologies that make civic data collections available for multiple uses, e.g., strengthening local knowledge, informing policy, or fostering reuse through journalistic media. Civic data, in this study, are defined as any data—whether original or derivative and whether provided by public authorities or through civic tech projects—"providing citizens means and knowledge to act upon (. . .) local pressing environmental issues affecting them and future generations" (Hamm, 2022: 13). Because the conditions of the stakeholders, available resources, and scope of civic tech and citizen sensing projects can vary greatly in practice, we propose a comparative analytical framework that addresses common elements across typical stages of such projects: 1) co-creation methods for the identification and alignment of stakeholders; 2) data interface designs for different types of uses (and users); and 3) models of impact pathways for mainstreaming civic tech and citizen sensing approaches through affiliations with policy, journalism, or local governance. The article will draw on illustrative examples from local and global civic tech and citizen sensing initiatives. Section 2 presents definitions of key concepts, and Section 3 presents the three core elements of the research agenda.

## 2 Civic tech, digital civics, and citizen sensing as niche innovations

Niche innovations are defined by Geels (2004) as "'incubation rooms for radical novelties." They can be "small market niches" or "locations where it is possible to deviate from the rules in the existing regime" (2004: 912). Civic tech and citizen sensing are examples of such niches. From the perspective of activists, civic tech is a heterogenous, global movement, which seeks to critique, build, and use digital technologies for civic purposes. It encompasses such diverse practices as prototyping new data platforms or lobbying for open software and transparent platform governance (e.g., through institutions like the Open Knowledge Foundation, Mozilla Foundation, and Wikimedia Foundation).

However, Schrock (2019) cautions that civic tech is difficult to define only as an activist movement since it covers a range of practices that seek to "humanize technology and integrate it within systems of governance to improve social conditions" (127). Civic tech often exhibits an interventionist (or "hacker") ethos that "situates administrative reforms as participation" (128), using technological interventions as an instrument of reform and instance of critique of public digital solutions. In what Schrock calls "technical pluralism," civic tech interventions are always political, combining hacking practices and technological development as well as community organizing (129). Civic tech activists seek to "open up space between government and community, changing the political system as a whole" (131) with a broad and inclusive understanding of (digital) public goods. For the US-American context, Cyd Harrell defines civic tech as "a loosely integrated movement that brings the strengths of the private-sector tech world (its people, methods, or actual technology) to public entities with the aim of making government more responsive, efficient, modern, and more just" (Harrell, 2020: 17).

Recently, civic tech has contributed to the design-led discourse and practice of "digital civics". Using "design as democratic inquiry" (DiSalvo, 2022), digital civics interventions "create relationships in participatory experiences between public officials and citizens based on mutual learning, empowerment, and co-creation" (Corbett et al., 2018: 9). They are often initiated by designers, activists, and researchers to address social and political inequalities affecting local communities. The approach is often participatory, experimental, and co-creative and uses technological designs as iterative contributions to broader processes of bottom–up "infrastructuring" (Le Dantec, 2016; Le Dantec, 2019). Importantly, digital civics "(aims) to support citizens becoming agents of democracy with and through technologies and in dialogue with the institutions that can actualize public will" (Vlachokyriakos et al., 2016: 2). In the context of smart city developments, for example, civic tech activists are a "political pioneer community" for creating responsive and sustainable civic infrastructures (Bieber, 2018: 190). These interventions allow citizens to assume varying roles and degrees of involvement (Przeybilovicz et al., 2022) to foster "collaborative city-making" (de Lange and de Waal, 2019).

Civic tech and digital civics converge with citizen science approaches in the growing field of projects around citizen sensing. This development can be attributed to the availability of low-cost, easy-to-use sensing devices for measuring environmental conditions as well as the widespread use of mobile, digital media in everyday lives of citizens (Goodchild, 2007; Gabrys, 2014; Gabrys, 2019; Coulson et al., 2021). Using smartphone apps, data platforms, or other (often self-built) technologies, citizens are invited to contribute to knowledge creation. Citizen sensing allows, to a certain degree, a "democratization of data" on environmental conditions (Coulson et al., 2021: 2) by employing citizen science principles to the communal collection and interpretation of data. Academics and practitioners in this field regard citizen sensing as a "modality of citizenship that emerges through interaction with computational sensing technologies used for environmental monitoring and feedback" (Gabrys, 2014: 32). Citizen sensing projects introduce new communal and data-driven practices that could "*complement* institutional monitoring of risks" (Suman and Anna, 2018: 260.) and are interesting from a research perspective because they link citizen empowerment with technological innovations to policy development.

Given the fair recency of many of these approaches, though, D'Ignazio and Zuckerman caution that "the world of science, journalism and communities using environmental data and sensors is a messy one" (D'Ignazio and Zuckerman, 2017: 201). Recurrent concerns about the impact of citizen science and civic tech projects relate to the quality of data, citizens' skills and competences to work together, to political biases in project designs, and missing opportunities for trainings (Callaghan et al., 2019; Strobl et al., 2019; Stylinski et al., 2020). Balancing civic, journalistic, or scientific goals often results in collecting only "good enough data" (Gabrys et al., 2016). We propose to assess citizen sensing projects at different stages from the perspectives of design, implementation, and legacy and impact (Coulson et al., 2021).

On a design level, the use of co-creation methods for multi-stakeholder alignment contributes to a project's development of objectives and desired outcomes. On an implementation level, interfaces for making data and knowledge available for different types of users can broaden a project's relevance and reach. On a legacy and impact level, different pathways can involve researchers and journalists, policymakers, or non-governmental organizations to contribute to local capacity-building through experimentation (Brynskov et al., 2018). In the following sections, we will briefly outline each of these elements that contribute to understanding the processes of mainstreaming civic tech and citizen sensing approaches.

## 3 Future research agenda: co-creation methods, data interfaces, and impact pathways

### 3.1 Co-creation methods for stakeholder alignment

The development of sensing scenarios, identification of empirical approaches, and the possible design of appropriate equipment often take place in a co-creative and transdisciplinary effort involving designers, citizens, researchers, municipal actors, or even policymakers. To achieve concrete "ramifications" (Hamm, 2022; Shibuya et al., 2022) for civic tech and citizen sensing projects beyond their runtime, the design of co-creation methods needs to include dedicated communication channels from the ideation to the implementation phase. As Hecker and Taddicken show in their framework and typology of citizen science projects, researchers' roles are challenged in co-creative arrangements, where communication on very different levels changes traditional and professional norms of science communication (Hecker and Taddicken, 2022). For example, in the Japanese project Safecast, social media was used to maintain multi-stakeholder communication and recruit engaged citizens (Hamm et al., 2021). Examples like the NEWSERA project also demonstrate that the interests of citizens and journalists may differ widely and need to be aligned through mutual learning, co-creating possible outputs from a project rather than only communicating its outcome. Inclusive designs of co-creation methods are a core challenge, especially for target groups not accustomed to assuming public speaker roles (Paleco et al., 2021).

### 3.2 Data interfaces

Citizen sensing projects are centrally concerned with different forms of data work and thus need to consider the different stages of data throughout a project's life cycle. In each stage, the "data setting," as Loukissas has coined it (Loukissas, 2019), is always "local": data are generated and interpreted by the involved stakeholders, serving their different purposes. Designing interfaces for these different stages and purposes is crucial for achieving a project's legacy and impact. We identify three levels of interface design that need consideration in research and practice.

#### 3.2.1 Interfaces for data collection

The design of inclusive, understandable, and reliable interfaces of data collection (through manual inputs, semi-automatic data mining, or sensing and detection kits) is a technical core challenge, implemented by technical experts. Low-cost sensor kits have flourished, especially in the domain of air quality/noise monitoring, yet setting up kits still relies on considerable technical expertise. Interfaces for data collection can also be included in websites and smartphone apps, e.g., by making use of native GPS sensors for metadata collection. Data collection can also simply use interfaces and features of social media platforms to share photos that are automatically analyzed (Cervone et al., 2016). Contributions from citizens can also be delegated to free apps that are already on the market, e.g., PIRIKA, which features an app to improve cleanliness of urban spaces. Although, in principle, such apps are publicly accessible, we have to ask who is contributing data to a project and who is excluded from it. It is important to understand not just the technical reasons, lack of skills, or knowledge but also the social and systemic ones that create biases for the resulting data and knowledge.

#### 3.2.2 Interfaces for output and communication

The output and communication level of interfaces needs to be attuned to the needs and competences of designated target audiences. Here, it can be useful to seek collaborations with interface and information designers, as well as data journalists. Collaborating for the output and public communication of civic tech and citizen sensing projects can also raise conflicts, particularly when complex datasets are visually simplified. Activists, journalists, scientists, and policymakers may apply different standards for the data they need. Activists often tend to underline their political agenda with visualization or "counter mapping" techniques (Bowe, Simmons, and Mattern, 2020; Hamm, 2020), whereas scientists rather visualize the complexity (and ambiguity) of phenomena (Marx, 2013). Prior work has emphasized that interface design also needs to consider different types of users and provide export formats for later uses of the data in different contexts (Shibuya et al., 2021; Vornhagen et al., 2021; Young et al., 2021). Such demands are not easy to fulfill by civic tech initiatives themselves, where resources and time for the design of interfaces are often rather limited.

One popular interface for exploring civic tech data is data dashboards, which can be used to address local issues through interactive data analysis, policy advice, and real-time monitoring (Williams, 2020; Goodwin et al., 2021). Depending on the use case, dashboards can have various underlying epistemologies built into their architecture and interface, which may not be obvious for citizens or lay audiences (Sadowski, 2021; Vornhagen et al., 2021; Young et al., 2021). Interfaces for public outreach and communication (e.g., dashboards, data maps, or websites) need to embed accessible graphic designs and can also use data-driven narrative forms, e.g., scrollytelling journalism that combines a focus on data and narrative form in an intuitive user interface. Interfaces can also highlight the community-driven nature of data collection, e.g., maps by the global Sensor.Community for tracking air pollution (sensor.community). In Japan, a community-developed COVID-19 dashboard visualized crowd-sourced, daily updated information about critical pandemic-related indicators (e.g., local COVID-19 testing of positive cases and hospital bed occupancy rates). In Taiwan, mask maps were developed by civic tech initiatives, allowing citizens to check on mask inventory levels in their neighboring areas to mitigate mask panic-buying behaviors (Shibuya et al., 2022). Whether as a map, a dashboard, or a data repository, each output form enables and limits subsequent uses of data, shaping the impact of a project.

### 3.2.3 Interfaces embedding data standards

Civic tech projects tend to focus on the collection and communication of case-specific data rather than using established metadata frameworks, which would allow data from different cases to be comparable and fulfill scientific quality standards. Open-source repositories for software scripts (such as GitHub), the global civic tech field guide platform (https://civictech.guide), or open-data collections (such as Zenodo) need to be considered from a project design perspective to enable capacity-building and transferability of methods between use cases and projects. Standardizing data collection procedures (e.g., for monitoring uses of public spaces or environmental conditions) can be achieved by employing metadata standards formulated in Public Participation in Scientific Research (PPSR Core) by the Citizen Science Association (CSA) or employing FAIR principles to enhance the findability and reusability of data assets (Wilkinson et al., 2016). Researchers can help translate standards into the practice of citizen-oriented projects.

## 3.3 Impact pathways for mainstreaming civic tech and citizen sensing

Collaborations between civic tech activists, researchers, citizens, journalists, and policymakers signal new ways in which research contributes to tangible outcomes for society, especially in social sciences and humanities. From a research policy perspective, new collaborative arrangements between researchers and society are studied as "impact pathways" (Muhonen et al., 2019). In civic tech and citizen sensing projects, convergence and synergies arise between scientific, journalistic, and activist practices of knowledge production, enabling new kinds of data collection, fostering community-building, and creating new modalities of public engagement. Impact pathways and other multidimensional models of impact assessment (Passani et al., 2022) show how civic tech and citizen sensing approaches can be mainstreamed from niche innovations to contribute to changes in existing socio-technical regimes, e.g., in governance, education, or journalism (Geels, 2019).

Baack has argued that "civic technologies can be described as alternative ways of fulfilling functions traditionally described as "journalistic"" (Baack, 2015: 7), and differences between activist facilitator roles and journalistic gatekeeper roles often need to be negotiated in practice (Baack, 2018: 680). The close affinity between citizen-sensing projects and data journalism creates new impact pathways, although conservative interpretations of data journalism still prevail in practice (Beiler, Irmer, and Breda, 2020; Morini, 2023). For example, in the project "Unser Wasser" (Our Water), the German public broadcaster ARD collected citizen-sensed data about the decline of water bodies during the drought in Germany in 2022 and provided an interactive and informative data map co-developed with scientists. Journalistic routines remain focused on informing rather than engaging citizens (Appelgren and Jönsson, 2021). Online participatory journalism often remains under the control of journalists (Engelke, 2019), and new forms of crowdsourcing knowledge are still limited in scope (Aitamurto, 2016). Data journalists regard their work as contributing to public debates, e.g., by interpreting abstract data through visualizations (Boyles and Meyer, 2016; cf. Stalph and Heravi, 2021). When the sources of data journalism are based on civic data, new challenges emerge between the objectives of community empowerment and the commercial use of data by media outlets (Morini, Dörk, and Appelgren, 2022).

# 4 Outlook: mainstreaming citizen sensing

Civic tech and citizen sensing projects are often driven by engaged volunteers, community organizers, and/or researchers. The impact of such projects, though, often remains quite limited if they fail to contribute to local capacity-building or building institutional frameworks of participation that ensure their legacy (Cerratto Pargman et al., 2019). We suggest that a focus on co-creation methodologies, data interfaces throughout a project's lifecycle, and impact pathways are crucial elements and stages in such projects. The proposed research agenda seeks to facilitate knowledge exchange around such projects as well as offer an agenda for comparative, international research that addresses mechanisms and obstacles of mainstreaming citizen sensing. Lastly but crucially, we regard it as essential that questions of equity and inclusiveness of co-creation processes in civic tech and citizen sensing interventions (Paleco et al., 2021) will become much more central to such an agenda as niche innovations confront larger socio-technical regimes. Which actors contribute to such projects? How are marginalized groups addressed and engaged? Which issues of public concern lend themselves better to citizen sensing approaches than others? What organizational and occupational factors (e.g., in civic tech or journalism) can foster or impede the uptake of civic tech and citizen sensing approaches? These are some central questions this research agenda addresses for future research to pluralize inclusive understanding of knowledge creation, research impact, and civic empowerment.

# Data availability statement

The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author.

# Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

# Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



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# Sharing communication insights of the citizen science program *Plastic Pirates*—best practices from 7 years of engaging schoolchildren and teachers in plastic pollution research

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Engaging the general public in research processes through citizen science allows for innovative scientific studies and makes science accessible to the general public. Effective communication strategies are crucial for the success of such initiatives. The citizen science program *Plastic Pirates* investigated the plastic pollution of rivers and implemented a variety of communication strategies with participating schoolchildren, teachers, and youth groups (e.g., sport associations, scouts or educational vacation programs, representing approximately 6% of participating groups). These were continuously revised and adapted since its start in 2016. Without time-efficient communication and strategies to keep track of conversations, it would not have been possible to achieve the scientific and educational goals of the program, i.e., to help teachers increase the environmental awareness and scientific literacy of their schoolchildren, and to produce peer-reviewed articles based on the collected citizen science data. Communication within the *Plastic Pirates* program was divided into four distinct phases: 1) recruiting and motivating participants, 2) coordination and guidance of participants, 3) data reception and revision, and 4) sharing updates and results. Some of the obstacles that had to be overcome to achieve successful communication were e.g., time constraints to obtaining scientific data from the participants, the time lag between the active involvement of the participants and the actual data analysis and publication of results, and limited personnel resources available for communication efforts. Our recommendations for other citizen science practitioners include regular and transparent communication with the participants regarding their contribution, the use of adequate and various communication channels, shifting the workload from the participants to the coordinating team of a citizen science initiative, as well as offering feedback on the research findings to the citizen scientists, thereby disseminating the results of the program.

KEYWORDS

**citizen science, citizen science projects, public engagement with science, citizen science in schools, science communication, school teachers, youth groups**

## Introduction

Citizen science initiatives represent a promising approach to involve the general public in research processes and thereby answer novel research questions (Bonney et al., 2009). Effective communication between the initiators (usually people with a formal scientific education) and participants (usually members of the general public without a formal scientific education, Eitzel et al., 2017) is crucial for the success of citizen science initiatives (Hecker et al., 2018; Rüfenacht et al., 2021; Wagenknecht et al., 2021): Respectful, appreciatory, and efficient communication contributes to an increase of the participants motivation (Rotman et al., 2012; Anderson et al., 2020), ensures high data quality (Balázs et al., 2021; Dittmann et al., 2022), and facilitates participant feedback to the team coordinating the citizen science activity (Kieslinger et al., 2018; Rambonnet et al., 2019). Furthermore, it informs participants of results and outcomes of the initiative (de Vries et al., 2019; Probert et al., 2022). Communication can occur through various channels, in person or via digital communication (Rüfenacht et al., 2021). In this study we present the various communication strategies used in the *Plastic Pirates* program.

The *Plastic Pirates* are a citizen science program in which schoolchildren and youth groups collect data on litter pollution on riverbanks and in rivers within the European Union (https://www.plastic-pirates.eu/). The schoolchildren, youth groups and their teachers and youth group coordinators participate in the program by collecting litter data and samples during campaigns, which are 2-months long periods, taking place once or twice per year (according to the capacity of the coordinating team; Figure 1). The participants work in groups on different aspects of local litter, each group employs a specific method to respond their corresponding research questions. One group investigates litter quantities and the main material composition of litter, while another explores the surroundings to infer the principal source of litter found (Kiessling et al., 2019). Another group focuses on identifying certain single-use plastics to evaluate whether a European legislation aiming at reducing single-use plastic pollution actually reduces the quantities of these items in the river environment (Kiessling et al., 2023a). Finally, one group examines the litter floating at the water surface in the river by counting larger floating objects and sampling plastic particles smaller than 5 mm; (Kiessling et al., 2021). The program's target audience are schoolchildren and youth groups as the *Plastic Pirates* have a strong educational focus, including aspects of environmental education, scientific literacy, youth empowerment, and getting active to reduce the environmental plastic pollution problem. The age of participants for which the program was designed was 12 and older, although some elementary schools participated every year as well. Since the start of the project in 2016 more than 24,000 schoolchildren, teachers and other people participated in the program in eleven sampling campaigns (Table 1). During the lifetime of the project the size of the project team varied

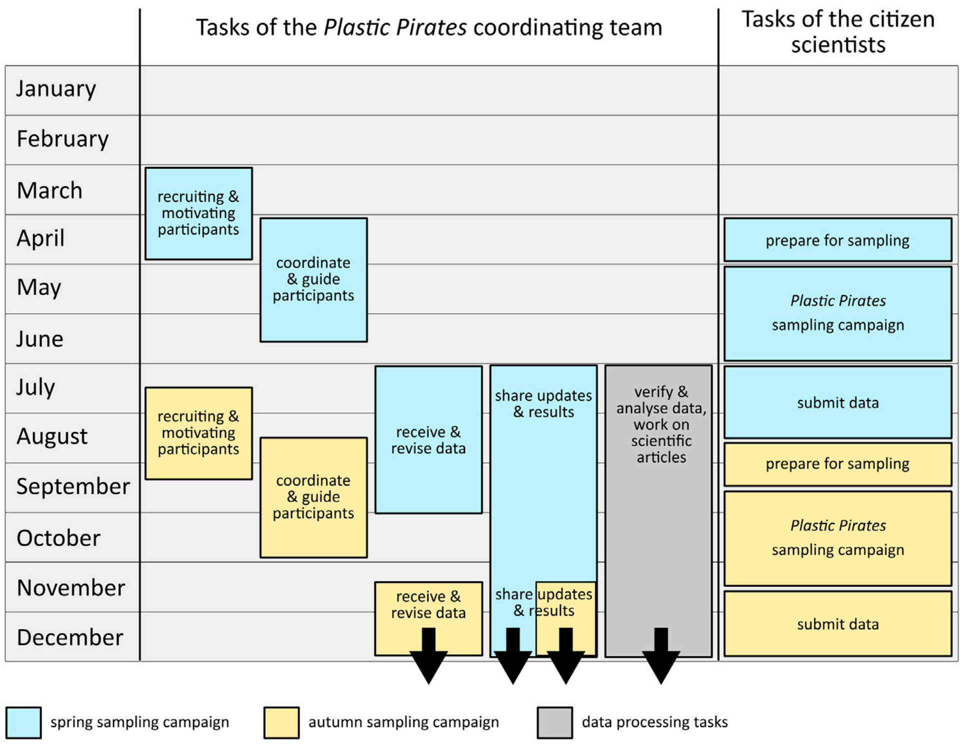


FIGURE 1
Tasks of the *Plastic Pirates* coordinating team and the citizen scientists in an exemplified year in which a spring and an autumn sampling campaign were conducted. Data processing tasks, such as citizen science data verification, data analysis and advancing work on scientific articles were loosely connected to the actual sampling campaigns and happened throughout the program. The black arrows indicate that work resulting from these phases was carried over to the subsequent year. The overlap of phases and the resulting workload for the coordinating team illustrates a main challenge of the *Plastic Pirates*.

TABLE 1 Number of groups requesting educational material, the microplastic sampling net, and submitting datasets for the eleven different sampling campaigns (2016–2023) of the *Plastic Pirates*. The last column shows the proportion of groups submitting a dataset compared to the number of groups ordering educational material. The sampling campaigns in the year 2020 correspond to the most severe COVID-19 restrictions in Germany. The number of participants is submitted by the teachers and youth group leaders.

| Sampling campaign | Educational material ordered (number of packages) | Sampling net ordered (number of packages) | Datasets submitted to the website [1] | Number of participants | Proportion of groups following through with sampling (%) |
|---|---|---|---|---|---|
| 2016 (autumn) | 858 | 200 [2] | 173 | 2,999 | 20 |
| 2017 (spring) | 784 | 200 [2] | 190 | 3,883 | 24 |
| 2018 (spring) | 428 | 133 | 107 | 1,960 | 25 |
| 2018 (autumn) | 470 | 167 | 137 | 2,223 | 29 |
| 2019 (spring) | 630 | 202 | 136 | 2,515 | 22 |
| 2020 (spring) | 312 | 60 | 40 | 153 | 13 |
| 2020 (autumn) | 368 | 144 | 82 | 1,520 | 22 |
| 2021 (spring) | 300 | 170 | 102 | 1,707 | 34 |
| 2021 (autumn) | 315 | 215 | 154 | 2,535 | 49 |
| 2022 (spring) | 396 | 237 | 173 | 2,991 | 44 |
| 2022 (autumn) | 226 | 144 | 97 | 1,585 | 43 |
| Total | 5,087 | 1,872 | 1,391 | 24,071 | 27 |
| Average | 462 | 170 | 126 | 2,188 | |

[1] A submitted dataset did not necessarily mean that it was considered in a resulting scientific article as it had to pass certain data verification steps (see Dittmann et al., 2022 for details): Kiessling et al., 2019 used 50% and 83% of available datasets, depending on the research question, Kiessling et al., 2021 used 43% and 81% of available datasets, and Kiessling et al., 2023a used 86% of available datasets.
[2] This value is estimated as there is only a combined number of an order of 400 sampling nets available for 2016 and 2017. According to our recollection, approximately the same number of sampling nets was ordered in each of those years.

substantially, ranging from one person being responsible for communication and data analysis to a team of two persons being involved in communication before the sampling and four to five persons responsible for the communication after the sampling and analysing data (all of which did not work full time in the program).

The *Plastic Pirates* are one among many citizen science initiatives investigating anthropogenic, and especially plastic litter: notable large-scale and international examples include the International Coastal Cleanup (Ocean Conservancy, 2022), Marine Litter Watch (EEA, 2022), the Marine Debris Tracker (Jambeck and Johnsen, 2015), and International Pellet Watch (Ogata et al., 2009). Citizen scientists have contributed substantially to our knowledge about plastic pollution (Hidalgo-Ruz and Thiel, 2015; Zettler et al., 2017; Kawabe et al., 2022). This global problem has reached unparalleled dimensions (Eriksen et al., 2023) with severe impacts to the wellbeing of natural environments (MacLeod et al., 2021), and it is expected that the scale of the problem will further intensify (Borrelle et al., 2020). While all environments are affected, rivers play an important role as a transport pathway of inland litter to the sea (Rech et al., 2015), and as a sensitive and polluted environment alike. This is no different for rivers in Germany, as the results of the *Plastic Pirates* have shown (Kiessling et al., 2019; Kiessling et al., 2021; Kiessling et al., 2023a).

This article describes the different communication phases and communication channels (telephone helplines, emails, postal mailings, social media posts, etc.) of the *Plastic Pirates* in Germany and explains how they were employed to achieve the main goals of the program: (i) generating novel scientific insights on the litter pollution of rivers, (ii) improving the scientific literacy and environmental awareness of the participating schoolchildren, youth groups and teachers, and (iii) raising the general publics' awareness of the plastic pollution problem. The communication strategies of the *Plastic Pirates* can be divided into four distinct phases: (1) recruiting and motivating participants, (2) coordination and guidance of participants, (3) data reception and revision, and (4) sharing updates and results (Figure 2). Phase (1) comprised communication efforts to recruit a sufficient number of interested school teachers and youth group leaders and motivate them to participate in the program. Phase (2) refers to the communication prior to data collection, with the aim of clarifying questions about the sampling methodology and organisational aspects of the program. Phase (3) relates to the communication after data collection, with the aim of ensuring that scientific data and associated metadata, photos, and samples were available to the coordinating team (i.e., the scientific team analysing and processing data), and to clarify questions regarding the quality of the citizen science data. Subsequently, phase (4) covers the communication of the results to the participants by providing feedback on the scientific insights to the participating schools as well as the general public. These communication strategies have been adapted and refined since the start of the program in 2016 and were essential for the success of generating novel data and insights about environmental litter pollution at riversides. Moreover, the communication strategies allowed the program to engage more than 24,000 schoolchildren in Germany.

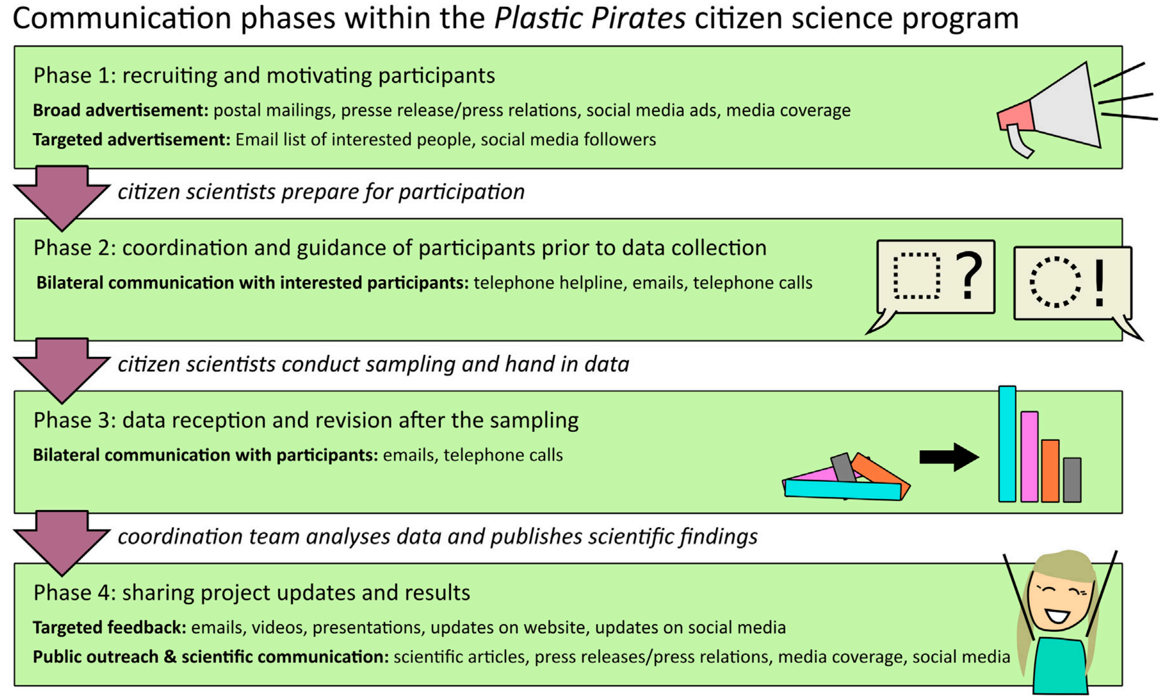


FIGURE 2
Communication tools used by the coordinating team of the citizen science program *Plastic Pirates* during the different communication phases with the participants.

## Phase 1: communication to recruit and motivate a sufficient number of participants

This first communication phase was implemented in advance of each *Plastic Pirates* sampling campaign. The sampling campaigns were usually conducted twice a year over a period of 2 months. During these campaigns data collection was the main objective (primarily to ensure comparability of data). To engage new participants, two main strategies were employed: (i) Addressing potentially interested school teachers, group leaders and the general public at large (broad communication), and (ii) a targeted outreach to people who previously showed interest in the *Plastic Pirates* (Figure 2).

Regarding the broad approach, a postal mailing was sent to approximately 25,000 schools around 2 months prior to the beginning of a sampling campaign. At the same time, the information about a new sampling campaign was advertised via the program's website, relevant web portals and newsletters about citizen science initiatives. Additionally, a professional communication agency was commissioned to do the press work for the program from 2016 to 2017. This led to more than 2,000 media reports throughout the lifetime of the program, including newspaper articles, online articles, radio features and contributions on national television channels (however, due to a lack of data of these media reports we were unable to evaluate the success of these measures in regards to recruiting participants). A study by Giardullo et al. (2023) has shown that 85.3 % of citizen science projects surveyed in the EU, United Kingdom and Switzerland used social media as communication medium for their projects, indicating the importance of digital communication tools to reach large target groups (Giardullo et al., 2023).

For the targeted outreach effort an email distribution list with approximately 2,000 email addresses was used, consisting of former participants as well as individuals who had contacted us to express their interest in the program. Moreover, posts on Facebook and Instagram informed followers about each new sampling campaign. As a further measure, a dedicated teacher training was offered twice a year through an established online teacher training service, serving the purposes of advertising the program as well as preparing participants for sampling. Each of these teacher trainings attracted approximately 100 teachers on average.

In order to keep the barriers for participation as low as possible, there were no requirements for official registration. Instead, interested teachers and youth group leaders could access educational materials (a sampling booklet, Kiessling et al., 2022; and teaching materials, Knickmeier et al., 2022) on the *Plastic Pirates* website and order printed copies via an online form free of charge throughout the year. Subsequently they could make an informed decision on whether they would like to participate. For each sampling period, up to 6,000 sampling booklets were sent out to interested teachers and other parties (with a decline during the pandemic). The educational material has been conceptualized through close cooperation between scientists and school teachers, and contained information that provided orientation on this field of research to participating teachers. The educational material contained solutions for assignments, an indication on time requirements and recommended group sizes for exercises, as well as detailed lists of materials needed for experiments (Knickmeier et al., 2022).

As a secondary step, informed and interested people would order a sampling net by providing the name, address and email of their institution, as well as the date they intended to sample with their school class or youth group. As the sampling net was costly, its shipment was restricted to participants who had acquainted themselves with the educational material. On average more than 450 people requested packages with educational material for each sampling period (containing up to 6,000 sampling booklets; Table 1), which translates to approximately 1.5%–2% of people addressed by the recruitment activities mentioned above. Overall the number of participants, materials ordered and datasets submitted varied with each sampling campaign. This was not only related to the success of communication strategies, but also influenced by external factors such as the COVID-19 pandemic (Table 1).

## Phase 2: communication to coordinate and guide participants prior to data collection

The second communication phase overlapped with the first phase, but extended into the sampling period (Figure 1). Here, the focus of communication was on bilateral exchange with teachers and youth group leaders who were seriously considering participating in the program. This phase included clarifying questions about the methodology, sampling, and organisational aspects of the program. Typical questions concerned the necessary size of groups and age of participants, sampling dates and sampling sites, required materials, and the suitability of the chosen river for sampling. At times these questions were asked before ordering the sampling material. Sometimes, however, these questions arose once the participants had acquainted themselves with the sampling material. Questions concerning the specific scientific methodology were asked less frequently.

Inquiries to the coordinating team could be posed via a telephone helpline that was active for 4 hours a day prior to and during the sampling campaigns, as well as via email (Figure 2). Most people used the second option, illustrating that this was the preferred mode of communication for teachers and youth group leaders in Germany. The value of this individual communication with each participant can also be exemplified by a survey that was conducted among *Plastic Pirates* teachers with the purpose to find out which factors motivated them to involve their class in a citizen science activity (Kiessling et al., 2023b): out of the 623 teachers invited, 153 teachers handed in a complete survey (26%, see the peak in March 2021 of invitational emails being sent in Figure 3).

To ensure that participants were able to conduct the sampling independently, i.e., without the presence of members of the coordinating team, the sampling booklet served as a hands-on guide for preparing of the field trip and for the actual sampling procedure (Kiessling et al., 2022). By dividing the sampling into five subgroups, the complexity of the individual samplings was reduced. Concise lists with the most important information (e.g., information boxes with a list of needed materials) further served to eliminate ambiguities.

## Phase 3: communication to receive and revise data after sampling

Once a school or youth group had completed the actual data collection, the next phase of communication was immediately initiated by the coordinating team after their sampling event (Figure 1). This was the most critical, time-sensitive, and work-intensive phase of communication as data and samples had to be secured and ambiguities about the data, such as missing metadata, had to be clarified as soon as possible (see also Dittmann et al., 2022 for concerns regarding the citizen science data quality of the *Plastic Pirates* program). Therefore, the communication effort via email usually reached its peak directly after the sampling campaign (Figure 3), resulting in an extraordinary workload especially in years with two sampling campaigns (2018, 2021 and 2022, though not 2020 due to COVID-19).

The coordinating team contacted school teachers and youth group leaders either after the intended sampling date (communicated by the participants while ordering the materials) or once a dataset was uploaded to the *Plastic Pirates* website. This phase of communication had three main goals: (i) assistance in data submission, (ii) data screening and immediate clarifications, and (iii) data validation.

For the first goal, participants uploaded their dataset making it publicly accessible on the website. The total amount of submitted and accessible datasets was an important public indicator for the success of a sampling campaign. Most issues here were caused by "unconfirmed datasets" as teachers and youth group leaders were required to publish their submitted dataset via an email link they received, a necessary extra step due to data protection regulations. Another issue was caused by missing data and material that was required when submitting a dataset to the website. We assume that the latter was mostly related to a lack of time among participants to organize and process meta-data, data about litter findings, and photos in the requested way. Therefore, in specific cases we offered teachers to submit their data and material via email, thereby shifting the workload of sorting data adequately, correcting sampling coordinates or resizing photos to fit the image size requirements away from the participants and towards the coordinating team.

The second goal was to screen the submitted data and photos for completeness and inconsistencies and to contact the teachers as quickly as possible to clarify these issues. Difficulties related for example to, for example, data sheets that were only partially filled out, photographs with unreadable labels or with a poor resolution, or coordinates that were not located close enough to a river to identify the actual site that was sampled. Due to the large number of participants and submitted datasets, it was challenging to screen the data in a timely manner. The sampling campaigns organized in spring were highly time sensitive due to the summer vacations and the transition to the next school year. In our experience, untimely communication resulted in data, photos and samples being lost, e.g., because images were deleted from smartphones, datasheets were discarded at the end of the academic year, the samples were lost during cleaning of the classrooms by uninstructed personnel, or teachers and schoolchildren (holding required information) became unavailable due to changes in class or school constellation.

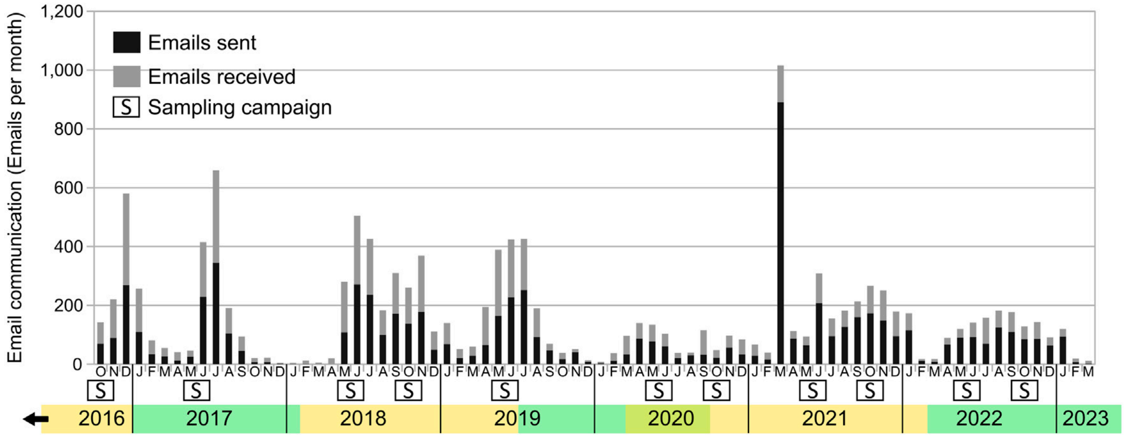


FIGURE 3
Numbers of emails sent and received per month by a centralized email address created for individual communication with participants, before, during and after the active data collection (i.e., sampling campaigns) of the *Plastic Pirates* (see Supplemental Material S1 for original data). The purpose of the individual communication was to coordinate the shipment of the microplastic sampling net, answering questions regarding the sampling, and getting in contact to obtain missing data and samples and clarify questions regarding the citizen science data quality. The six different funding periods, partially overlapping, are highlighted as bars overlaying the indication of years. In total 12,767 emails were registered (7,237 emails sent, 5,530 emails received). This represented a little more than 1,000 h of work, assuming every email required 5 minutes of attention, and therefore approximately 37 weeks of employment time (given a work contract typical of the program of ~29 h per week). The peak of emails being sent in March 2023 is due to individualised invitations to participate in a survey (see main text of the manuscript).

The third goal, the data validation, was not as time sensitive in terms of communication, as all data and materials were either obtained from participants or deemed to be unobtainable after the first two steps. During this final step the citizen science data were verified, i.e., the submitted data sheets were compared to the photos showing the litter findings (see Dittmann et al., 2022 for details). This process sometimes led to open questions on the side of the scientists, such as whether empty sections of the data sheet indicated that there was no litter at this sampling station or whether this sampling station had not been established and investigated (Kiessling et al., 2019). Another example of clarifying communication during this phase was whether annotated floating litter was actually mobile, or whether it was immobile and had become entangled in the vegetation (Kiessling et al., 2021).

## Phase 4: communication to share updates and results

The final phase of communication aimed to inform participants about the results and progress of the program. The major challenge of this phase was the time difference between data collection and the actual publication of scientific results, particularly the publication of a study investigating microplastics which required thorough visual analysis of each sample and the polymer characterization of each microplastic particle (Kiessling et al., 2021; Table 2). These long times between being involved in an activity and seeing actual results was difficult to convey to the participants, especially given the fast-paced school environment.

Due to this, the program was designed to offer closure to participants before the publication of scientific articles by employing different strategies: (i) The sampling booklet encouraged participants to compare their own results with data collected by other groups (Kiessling et al., 2022). This was done using the website, which automatically showed a summary of uploaded data of all groups and calculated means of litter findings (Supplemental Material S2). We chose this fast access to data summaries over data quality as the verified data would only be available much later in the process (see Phase 3). (ii) The educational material further contained an optional chapter on how to get involved in solving the plastic pollution crisis, in case teachers wanted to encourage interested schoolchildren to pursue the problem beyond the collection of data (Knickmeier et al., 2022). (iii) A certificate of participation was sent out to participating teachers (usually about 2 months after the end of a sampling campaign). During the first campaigns, the certificate was a printed document, during later campaigns, however, the certificates were sent via email, due to budget constraints. (iv) Program updates were posted on social media, providing participants with a behind-the-scenes look. This additional work (attending social media) illustrates the challenges faced by the coordinating team (e.g., meetings with project partners to prepare the sampling campaign, the time required for data reception and posterior analysis) and demonstrated why this was such a time-intensive process (Supplemental Material S3).

Once data were screened, we usually reported results in an abbreviated and summarized form on a dedicated section of the website (Supplemental Material S2). This took multiple months and was especially challenging in years with two sampling campaigns as this phase (Phase 4) overlapped with Phase 1 of the next sampling campaign (Figure 1). After full analysis, i.e. the publication of the respective scientific article, a summary of the article in German was sent to all participating teachers and youth group leaders and also disseminated via social media. This summary took different shapes, e.g. slides to be shown in class or short videos for schoolchildren to watch (Supplemental Material S3).

**TABLE 2 Time between citizen science sampling campaigns and the actual peer-reviewed publication of the respective *Plastic Pirates* study making use of these data.**

| *Plastic Pirates* study | Citizen science data collection campaigns | Published (available online) | Time between data collection campaigns and publication (counting from last sampling campaign of which data were considered) |
|---|---|---|---|
| Investigation of riverside litter quantities, composition and sources (Kiessling et al., 2019) | Autumn of 2016 and spring of 2017 | November of 2018 | Approximately 17 months |
| Investigation of microplastic quantities, polymer composition and sources (Kiessling et al., 2021) | Autumn of 2016 and spring of 2017 | May of 2021 | Approximately 4 years |
| Evaluation of the EU Single-Use Plastics Directive (Kiessling et al., 2023a) | Multiple campaigns from spring of 2019 to autumn of 2021 | April of 2023 | Approximately 18 months |

Apart from this targeted communication to participants, other stakeholders such as non-scientific groups (policymakers, environmental engineers, NGOs etc.) were also informed of the outcome, e.g., through non-scientific technical reports (Dittmann et al., 2021; Dittmann and Kiessling, 2021; Mederake et al., 2021) as well as press work which resulted in print, online and broadcast media coverage.

## Discussion

Being a mostly *contributory* program (as opposed to *co-designed* citizen science initiatives, Senabre Hidalgo et al., 2021) the communication processes in the *Plastic Pirates* program were largely designed to ensure that (i) participants can effectively learn about the scientific process and the plastic pollution problem, and (ii) scientifically useful data about the litter pollution of rivers could be collected and submitted by participants. The purpose of communication within citizen science initiatives varies depending on e.g., the desired outcomes, target audience, timescales, and the level of engagement of the participants in the initiative (Rüfenacht et al., 2021). For initiatives engaging their participants in the design of research questions (Ballard and Belsky, 2010), in extensive training to perform data collection and the shipment of samples (Schneider et al., 2021), the analysis of data (Weigelhofer et al., 2018) or even the publication of results (Nicosia et al., 2014), individual communication naturally starts much earlier and ends much later in the lifetime of a citizen science initiative. Stronger, deeper interaction has been shown to lead to a stronger participant commitment (Rüfenacht et al., 2021). For the *Plastic Pirates* program, a more co-creative approach would not have resulted in the large number of participants (who were geographically dispersed across Germany). Much of the coordinating team's resources were already allocated to communication and data quality assurance efforts (Figures 1, 3; Dittmann et al., 2022).

Regarding the workload, the third phase of communication, the reception and revision of data, was the most complex within the *Plastic Pirates* program, but essential for the achievement of the program's main goals. Especially in years in which two sampling campaigns were conducted, the follow-up phases of one campaign (Phase 3) and the preparation phase of another (Phase 1) often overlapped (Figure 1). Other citizen science initiatives overcome this demanding workload by relying on technology to involve participants or other interested parties in processes such as the verification of data (e.g., iNaturalist, di Cecco et al., 2021, see also the citizen science app SPOTTERON, which offers a platform for various citizen science initiatives, Hummer and Niedermeyer, 2018). For the *Plastic Pirates* program the development of an app would have been too costly, and school classes in Germany are currently insufficiently digitized to allow for data collection via mobile devices in the field. Furthermore, subsequent communication between teachers or youth group leaders and the coordinating team for the purpose of clarifying questions would not have been resolved via an app as many issues could only be clarified bilaterally via email or telephone.

A further challenge was providing feedback to teachers and youth group leaders after participation, as the publication of the scientific articles took over 1 year after datasets were submitted (Table 2). In *contributory* initiatives timely feedback of results is important for participants to gain insights into the scientific findings, to which they had contributed (de Vries et al., 2019), which is why we chose to share insights into the scientific process via social media.

Feedback can be a very important motivating factor for participants (Rotman et al., 2012). The only possibility for feedback for teachers and youth group leaders in the *Plastic Pirates* program was direct contact with the coordinating team. Here, a central platform with the purpose of building a community would have given participants a chance to reflect upon their participation and interact with each other. The predecessor of the *Plastic Pirates* program, the project *Following the Pathways of Plastic Litter,* engaged classes in community building exercises through an online blog and through sharing experiences via video and texts. Still, there was a moderation and language barrier between the two participating countries (Chile and Germany), which was challenging to overcome and time-consuming for the coordination team (Kruse et al., 2020). Similarly, short funding periods (Figure 3) and uncertainties about future funding made the communication with participants even more difficult, as we (the coordination team) could only offer ambiguous responses to the questions of teachers whether future participation was possible, had no certainty in planning these future campaigns, and submitted data were not fully analysed yet.

It has to be emphasized that we see the motivation of the participants and the integration of their particular interests and knowledge, as well as their involvement beyond data collection within the research approach as an essential component of citizen science. Therefore, extensive educational materials were prepared that could be used mostly independently by participants (Kiessling et al., 2022; Knickmeier et al., 2022). Educational material or data collection protocols are an integral part of many citizen science initiatives and it is important that their format is adapted to the target audience (Balázs et al., 2021).

Overall the success of communication strategies varied, which could be seen in the ranges of people ordering materials and participating in sampling excursions in different years, and was also influenced by external factors such as the COVID-19 pandemic (Table 1). Over the long duration of the program in Germany (more than 6 years to date), the communication strategies used within the *Plastic Pirates* were constantly adapted based on our experiences. This included, for example, keeping track of conversations with the help of a spreadsheet (annotating missing information alongside dates when participants were contacted), simplifying sampling protocols, and establishing the backend of the website in such a way that the coordinating team could easily access information about datasets (e.g., upload data, check for missing photos, ensure accuracy of metadata). These improvements along with frequent individual conversations with teachers and youth group leaders with the purpose of achieving the scientific goal of the initiative, illustrated the value of the citizen scientists' contributions and resulted in effective communication strategies within the *Plastic Pirates* program going forward.

## Recommendations for citizen science communication strategies

Our experience with the *Plastic Pirates* program showed that quick and efficient individual communication with participants (usually teachers and youth group leaders), mostly via email, was key for obtaining and verifying citizen science data. We would have preferred to systematically involve participants in an evaluation of the program's communication strategies and include them in the more scientific processes of the *Plastic Pirates* program (such as verifying each other's datasets), and digitizing educational materials (or developing an app). However, due to financial and time-constraints, we focused on the key mission of the program, namely, offering participants a short-lived scientific experience beyond the typical classroom activities, and gathering novel insights into the problem of environmental plastic pollution. Because of this, we were able to convey scientific findings based on citizen science data in several peer-reviewed publications (Kiessling et al., 2019; Kiessling et al., 2021; Kiessling et al., 2023a), share our lessons learned regarding data quality mechanisms of the program (Dittmann et al., 2022), involve more than 24,000 participants in Germany, who contributed more than 1,200 datasets of litter pollution, and extend the spatial scope of the program beyond Germany to other European countries (https://www.plastic-pirates.eu/). The main challenge to be overcome was balancing the limited personnel resources of the coordination team with the need for individual communication with participants after the field sampling for the purposes of receiving data and reviewing data quality. While successful citizen science communication strategies are tied to the goals of individual initiatives, we offer the following ten best practice tips based on the experiences of the *Plastic Pirates*, which might be especially valuable for similarly structured contributory citizen science initiatives:

(i) Communicate as flexible as possible and in a transparent and concise manner to ensure scientifically valuable data.
(ii) Make sure to have the extensive personnel resources needed for efficient communication.
(iii) Keep the barriers for participation as low as possible by offering material free of charge and shifting workload from participants to the coordinating team.
(iv) Ask for sampling dates in advance to anticipate data processing efforts at an early stage.
(v) Offer an alternative way to submit data, as for some participants the barrier to submit data via a dedicated web form can likely not be overcome, for the alternative use a communication medium the participants are familiar with.
(vi) Assist participants during work phases requiring technical skills or tasks that are repetitive.
(vii) Keep participants engaged and communicate with them beyond the data collection phase.
(viii) Acknowledge the value of the contributions of participants (in publications or social media posts) and celebrate achievements together, for example, upon reaching important milestones (see Supplemental Material S3).
(ix) Ensure that communication with teachers (e.g., in form of telephone helplines or webinars) is available outside of school hours (in the afternoon or evening).
(x) Consider the realities in which schools operate, e.g., vacations, teaching schedules and formats, school curricula, available personnel resources and time constraints.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

## Author contributions

SD and TK conceived the presented idea. SD, TK, LM, MH, and MT discussed the implications of the findings and wrote the initial draft of the manuscript. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1233103/full#supplementary-material

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# From goals to engagement—evaluating citizen science project descriptions as science communication texts

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**Introduction:** Attracting and recruiting volunteers is a key aspect of managing a citizen science initiative. Science communication plays a central role in this process. In this context, project descriptions are of particular importance, as they are very often, the first point of contact between a project and prospective participants. As such, they need to be reader-friendly, accessible, spark interest, contain practical information, and motivate readers to join the project.

**Methods:** This study examines citizen science project descriptions as science communication texts. We conducted a thorough review and analysis of a random sample of 120 English-language project descriptions to investigate the quality and comprehensiveness of citizen science project descriptions and the extent to which they contain information relevant to prospect participants.

**Results:** Our findings reveal information deficiencies and challenges relating to clarity and accessibility. While goals and expected outcomes were frequently addressed, practical matters and aspects related to volunteer and community management were much less well-represented.

**Discussion:** This study contributes to a deeper understanding of citizen science communication methods and provides valuable insights and recommendations for enhancing the effectiveness and impact of citizen science.

KEYWORDS

**participatory research, popular science writing, science communication, science and society, open science, public engagement with science**

## 1 Introduction

As citizen science continuously grows and establishes itself as an independent field of scholarship, questions regarding its implementation, impact and sustainability arise. In many cases, practices from science communication have proven useful in promoting and organizing citizen science projects, streamlining communication with participants, and ensuring their needs and ideas are considered. Practices such as storytelling, data visualization and co-creation are gaining increased attention in the citizen science landscape with calls to consistently incorporate these practices into project design and implementation. Storytelling, for example, can help communicate complex scientific concepts to a wider audience and foster greater engagement and understanding among citizen scientists (Hecker et al., 2019). Data visualization can enable citizen scientists to more easily understand and interpret scientific data (Sandhaus et al., 2019; Golumbic et al., 2020) and co-creation can help build trust and collaboration between scientists and citizen scientists, whilst attending to the needs of both groups (Gunnell et al., 2021; Thomas et al., 2021).

A key element in leading a citizen science initiative is attracting and recruiting volunteers. Naturally, science communication plays a central role in this process. A successful citizen science project requires a strategic approach to volunteer recruitment, including identifying target audiences, developing compelling communication and training materials, and leveraging a range of channels to reach potential participants (Lee et al., 2018; Hart et al., 2022). Citizen science platforms, such as SciStarter (https://scistarter.org) and EU-Citizen.Science (https://eu-citizen.science), serve as key entry points for many citizen scientists as they allow users to explore a diverse range of projects (Liu et al., 2021). Within these platforms, projects are given the opportunity to introduce themselves to potential participants and provide valuable information about their goals and activities relevant to future volunteers. Often, citizen science platforms are central components in a project's online presence and serve as the first point of contact between a project and prospective participants. While some platforms present the information provided by project representatives in a structured or semi structured way (which is typically determined by the submission forms used for data entry), others have adopted a less pre-structured format. What all platforms have in common, is that they offer the choice to include a free-style project description, which according to Calvera-isabal et al. (2023), is the key source of information about citizen science projects openly available online. As such, information provided in these descriptions should be presented in an easy-to-understand and engaging manner, providing all the relevant practical information, while also sparking readers' interest and motivating them to join. It is furthermore essential to explain how potential participants may benefit from their involvement, and to make the project description as a whole reader-friendly and accessible.

There is a growing body of literature in the field of science communication that focuses on effective ways to convey scientific information to non-scientific audiences. Generally speaking, popular science writing often employs a contrasting structure to that of scientific academic writing. While academic writing tends to follow a pyramid structure with much background and detail upfront, popular science writing often employs an inverted pyramid structure similar to news and journalism standards (Po¨ttker, 2003; Salita, 2015). The inverted pyramid arranges content according to its newsworthiness, beginning with the conclusions and bottom line, followed by additional information in descending order of relevance (Rabe and Vaughn, 2008; Salita, 2015). Additionally, popular science often incorporates a range of rhetoric styles, such as storytelling, humor, collective identification and empathy, and strives to decrease the use of jargon and technical language (Bray et al., 2012; Rakedzon et al., 2017). Similarly to popular science writing, project descriptions are texts intended for general audiences and would benefit from adopting science communication practices in their structure.

Over the past 2 years, several studies have been conducted within the CS Track consortium that investigated citizen science project descriptions using a variety of different approaches and methods. CS Track is an EU-funded project aimed at broadening our knowledge of citizen science by combining web analytics with social science practices (De-Groot et al., 2022). In this context, project descriptions were analyzed from various angles, examining participatory, motivational and educational aspects reflected in the descriptions' texts (Oesterheld et al., 2022; Santos et al., 2022; Calvera-isabal et al., 2023). This work revealed that citizen science project descriptions vary significantly in terms of content, length and style. Some are extremely short and contain very little information on project goals or concrete activities citizen scientists will be expected to engage in. Others provide lengthy and jargon-laden explanations of the project's scientific background that are difficult for non-experts to understand. Similar findings have also been described by Lin Hunter et al. (2020) in the context of volunteer tasks as presented in project descriptions on the CitSci.org platform. In light of these observations a set of evidence-based recommendations for writing engaging project descriptions was developed, in the form of an annotated template. This template lists ten essential elements of effective project descriptions and provides text examples for each element, as well as offering general advice on length, format and style (Golumbic and Oesterheld, 2022). Designed as a tool for citizen science project leaders and coordinators, the template has been piloted in a series of online and face-to-face workshops, where it received positive feedback.

In this paper, we aim to examine the information deficits in project descriptions that we described above in a more systematic and quantifiable manner. We ask, to what extent do citizen science project descriptions contain information relevant to prospect participants, and is this information presented in a comprehensible manner? To answer these questions, we conducted a thorough review and analysis of a sample of citizen science project descriptions, with a focus on identifying and categorizing key elements related to project scope, objectives, methods, volunteer management, community engagement, and more. Using content analysis, we quantified the prevalence of these characteristics within project descriptions, identifying deficiencies and areas that lack clarity in their communication to potential participants. The findings of this study will contribute to a deeper understanding of citizen science communication methods, identify areas for improvement and will inform the development of more effective science communication strategies for the recruitment of volunteers.

# 2 Materials and methods

## 2.1 Rubric development

The coding rubric used in this study is based on the project description template the authors developed as a resource for the citizen science community (Golumbic and Oesterheld, 2022). As described above, the template lists and exemplifies ten essential elements for writing engaging project descriptions. The development of the project description template was informed by research conducted in the CS Track consortium in order to extract information about citizen science activities in Europe from project descriptions stored in the CS Track database. In conjunction with the citizen science and science communication literature, ten essential elements were identified which jointly contribute to making a project description engaging and effective. Table 1 details the essential elements identified and their justification for being included in the rubric.

**TABLE 1 Ten essential elements to be included in citizen science project descriptions.**

| Project description element | Explanation | Purpose | Supporting literature |
|---|---|---|---|
| One-sentence overview | The essence of the project summed up in a concise manner—ideally in one sentence in the beginning of the description | to clarify the project's purpose and scope<br>to quickly capture the attention and interest of potential participants | Rabe and Vaughn (2008), Hut et al. (2016) |
| Goals | Clear and explicit description of the projects' direct goals and objectives. Goals may be scientific, social or policy-oriented | to help readers understand the project's aims and expected outcomes<br>to attract participants who value these objectives and therefore want to contribute to the project | Golumbic et al. (2019), Maund et al. (2020), Bonney et al. (2021) |
| Impact | Explanation of the projects' long-term contribution to solving a larger problem beyond the project's direct research question or goal | to help readers understand the value and long-term benefits of the project<br>to attract participants who share this vision and want to assist with solving the problem addressed by the project | Baruch et al. (2016), Wehn et al. (2021) |
| Activities/tasks | Description of the activities and tasks participants will be asked to do in the project. Including details on the location, time commitment, tools used, etc. | to help participants choose a project which aligns with their interests, skills and capacities | West and Pateman (2016), Hart et al. (2022) |
| Target audience | Details on potential participants, their relationship with project field or goals and the kinds of skills or knowledge they need to have | to help recruit participants who are a good match for the project activities and tasks<br>to appeal to participants' self -identity (e.g., as hiking enthusiasts, scuba divers, etc.) | Bonney et al. (2021), Hart et al. (2022) |
| Benefits of participation | Explanation on what citizen scientists may gain through their participation in the project | to motivate and incentivize participants to engage with the project<br>to demonstrate how participants' involvement will contribute to their personal growth | Baruch et al. (2016), Lee et al. (2018), Robinson et al. (2018), Maund et al. (2020) |
| Information on how to join | Concrete, practical information on how volunteers can join the project and start participating | to streamline the registration and onboarding of participants | Asingizwe et al. (2020) |
| Training & educational resources | Details on training, instructions or educational resources provided by the project | to demonstrate the support participants will receive throughout their involvement with the project<br>to raise participants' confidence in their ability to contribute effectively | Golumbic et al. (2019), Lorke et al. (2019), Bonney et al. (2021) |
| Access to results | Explanation of the ways in which project data and results are communicated or shared with the participants | to increase project transparency and accountability<br>to demonstrate to participants the outcomes of their contributions<br>to help sustain citizen scientists' motivation to continue participating in the project | Baruch et al. (2016), West and Pateman (2016), Robinson et al. (2018), de Vries et al. (2019), Golumbic et al. (2019) |
| Recognition for citizen scientists | Expression of gratitude or appreciation for the citizen scientists' contributions and/or an indication of the ways the project will acknowledge these contributions | to show appreciation for the hard work of participants<br>to promote a sense of belonging and pride in the project<br>to enhance the reputation and credibility of the project | West and Pateman (2016), Robinson et al. (2018), de Vries et al. (2019), Asingizwe et al. (2020) |

For the purpose of this study, the project description template was translated into a coding rubric (see Supplementary S1). Each element of the template was transformed into a categorical coding format, with clear definitions and examples for each category. While the "one-sentence overview" is a meta-level element that cuts across content-related distinctions, the remaining nine elements of the coding rubric can be grouped into three categories representing different dimensions of citizen science projects:

(1) the project's purpose and expected outcomes ("goals" and "impact")

(2) the project's method of operation ("activities/tasks," "target audience," "information on how to join," "training/educational resources")
(3) the project's volunteer and community management ("benefits of participation," "recognition for citizen scientists," "access to results")

For six of the ten elements—impact, benefits, information on how to join, training and educational resources, access to results, recognition—presence or absence was easily detectable. Therefore, a binary coding scheme (mentioned/not mentioned) was chosen. The remaining four elements—overview, goals, activities, and target audience—were more challenging to classify into two categories since even when present, the comprehensiveness and detail provided in the text did not always provide sufficient clarity as to the full element content. We therefore introduced a three-dimensional ordinal coding scheme (poor, fair, good). The full rubric (Supplementary S1) provides detail as to the differentiation between the 3 codes. For example, in order to qualify as a "good" description of project goals, these needed to be explicitly framed as goals using phrases such as: "this project aims to," "Our goals are," "the purpose of this project is." In cases where goals were implied but not made explicit, using terms such as "we are investigating," "we are compiling," "this allows us to," the respective descriptions were classified as "fair." Finally, descriptions where no goals were detected were classified as "poor." In order to increase the content-level granularity of our analysis, three subcategories were added for both "goals" and "impact" (scientific, social & educational, environment & policy-related), classified in the case "good" goals and "mentioned" impacts were found.

Once the initial rubric was designed and the meaning of each category defined, examples from existing project descriptions were used to populate the rubric and clearly differentiate between coding options. This was done through discussion and negotiation between authors and with the assistance of a third coder, an expert in computational content analysis, until full agreement was achieved.

Validity-checking of the coding rubric, ensuring it is fit for purpose and that all categories are well-defined and demarcated, was conducted with the assistance of 6 external researchers who were familiar with the research goals and context, yet were not involved in the rubric development. Researchers were presented with the coding rubric and asked to review and use it for coding two independent project descriptions. Following this process, results were compared and discussed, and where disagreement arose, the rubric was adjusted and revised.

## 2.2 Sample selection

A sample of project descriptions for this study was selected from the CS Track database (De-Groot et al., 2022; Santos et al., 2022), which aggregates data from 59 citizen science project platforms, collected primarily by an automated web crawler. In cases where a project was presented on more than one platform, it is listed here under the name of the platform it was first extracted from. At the time of writing this paper, the CS Track database contained information on more than 4,900 Citizen Science projects worldwide. The distribution of projects according to their platform source is provided in Table 2.

For the purpose of this study, we applied two filters to generate our sample (see Figure 1). First, due to the authors' language skills, we created a dataset containing only English-language project descriptions, resulting in a subsample of 2,949 projects. This excluded a number of major citizen science platforms from non-English speaking countries such as Iedereen Wetenschapper from the Netherlands, which accounts for 5.4% of project descriptions in the CS Track database, or OPEN Observatoires Participatifs des Espèces et de la Nature, which accounts for 5%. We then filtered all descriptions according to their word count (see Figure 2), descriptions which consisted of less than 100 or more than 500 words were excluded. This threshold was set as texts of less than 100 words cannot be expected to contain a significant amount of information. Project descriptions of more than 500 words are less likely to be read in their entirety than shorter texts (Meinecke, 2021) and thus ill-suited to the task of capturing the readers' interest and prompting them to join the project. This second round of filtering excluded an additional 1,666 project descriptions, leaving a dataset of 1,283 useable texts. The distribution of these projects according to their platform source was significantly different to that of the whole dataset, as can be seen in Table 2, with an abundance of projects from one platform (SciStarter).

Using this dataset, we created a random sample of approximately 10% of project descriptions by applying the "random" function of RStudio. In total, we analyzed the descriptions of 120 citizen science projects from 16 different online citizen science platforms. The distribution of the sample in terms of platform sources resembles that of the abridged 1,283-project dataset (see Table 2). During the analysis process, 6 project descriptions were excluded from the final sample because they did not contain any indication of engaging the public in research processes.

## 2.3 Coding

Following the establishment of rubric validity, 10% of the project description sample was randomly selected and independently coded by the authors and the third coder introduced above. Results were compared and discussed where disagreement occurred. This was followed by a second round of coding of an additional 10% of the sample.

To increase reliability of the results, and since at this stage intercoder reliability of over 90% of agreement was not established for all categories, an additional 10% of the sample was coded by all 3 coders, whilst highlighting specific places where coders were not confident of their coding decisions. Inter-rater reliability was calculated for all items, excluding those with low coding confidence, and was found to be over 90% for all categories. In those cases where coding was challenging, results were compared and discussed to reach full agreement. In total 36 project descriptions were coded by 3 independent coders. Calculations of the inter-rater reliability for each category, with and without the low confidence coding, are presented in Supplementary S2.

Following the coding reliability check, the remaining 80 projects were coded by one of the two authors. As in the last round of the

**TABLE 2 Platform distribution for the entire CS Track database, filtered dataset including only English-language project descriptions with a word count between 100 and 500, and the random sample used for the analysis of this study.**

| Platform name | Full CS Track database (N = 4,949) | | Filtered dataset (N = 1,283) | | Study sample (N = 120) | |
|---|---|---|---|---|---|---|
| | N | % | N | % | N | % |
| SciStarter | 1,675 | 33.8% | 858 | 66.9% | 72 | 60.0% |
| iNaturalist | 1,080 | 21.8% | 56 | 4.4% | 4 | 3.3% |
| Zooniverse | 361 | 7.3% | 72 | 5.6% | 11 | 9.2% |
| Iedereen Wetenschapper | 266 | 5.4% | 0 | 0 | 0 | 0 |
| Observatoires Participatifs des Espèces et de la Nature | 245 | 5.0% | 3 | 0.2% | 1 | 0.8% |
| Ciencia Ciudadana | 184 | 3.7% | 1 | 0.08% | 0 | 0 |
| EU-Citizen.Science | 144 | 2.9% | 112 | 8.7% | 11 | 9.2% |
| Österreich forscht | 74 | 1.5% | 0 | 0 | 0 | 0 |
| Schweiz forscht | 66 | 1.3% | 1 | 0.08% | 0 | 0 |
| Zentrum für Citizen Science | 63 | 1.3% | 55 | 4.3% | 7 | 5.8% |
| Science et Cité | 63 | 1.3% | 0 | 0 | 0 | 0 |
| Citizen Science Vlaanderen | 18 | 0.4% | 17 | 1.3% | 1 | 0.8% |
| nQuire | 36 | 0.7% | 17 | 1.3% | 1 | 0.8% |
| Natural History Museum United Kingdom | 13 | 0.3% | 10 | 0.8% | 3 | 2.5% |
| Open Systems UB | 16 | 0.3% | 11 | 0.9% | 2 | 1.7% |
| Other | 645 | 13% | 70 | 5.5% | 7 | 5.9% |

reliability check, coders indicated places of low confidence, which were then discussed to reach full agreement.

## 3 Results

To assess the quality and comprehensiveness of citizen science project descriptions found on online platforms, our analysis focused on 10 key elements contributing to engaging and effective project descriptions. In this section, we present the results of our analysis, which revealed several important aspects relevant to prospective participants that are missing in many project descriptions. Our results first present findings on the first key element—project overview, followed by the remaining elements divided according to the three dimensions of citizen science projects described above: 1. purpose and expected outcomes 2. methods of operation 3. volunteer and community management.

### 3.1 Project overview

A project overview is an important part of project descriptions as it provides a clear and concise summary of the project's main objective, scope, and expected outcomes. It can quickly capture the attention of potential participants and help them understand the purpose and value of the project and make a swift decision as to their involvement.

Yet, our analysis reveals that only 30 of the projects in our sample (i.e., 26.3%) begin their descriptions with a clear and concise one-sentence summary of the project (Figure 3). An example for a good project overview is: "[*Project name*] *is a network of citizen scientists that monitor marine resources and ecosystem health at 450 beaches across* [*name of place*]." In 38 cases (33.3% of our sample), a project overview was present, but either lengthy and unfocused or spread across two sentences. An example for such a lengthy and detailed project overview is "[*The project*] *needs volunteers to undertake surveys for grassland birds, such as* [*names of birds*], *along established routes and in managed grasslands, and to collect data on bird abundance and habitat characteristics*." A more extreme case is split into two sentences: "[*The project*] *was initiated in 1983 to provide a mid-summer estimate of the statewide* [*type of bird*] *population. On the third Saturday in July each year, volunteers survey assigned lakes, ponds, and reservoirs from 8:00 to 9:00 a.m., recording the number of adult* [*bird*], *subadult* [*bird*] *(1–2 year olds), and* [*bird*] *chicks on the water body, as well as relevant human and wildlife activity*." An additional 40.4% of project descriptions make no attempt to open with a project overview and instead dive straight into the historic or scientific background of a project. One project, for example, started by explaining that "*Scientists have flown over and systematically photographed the* [*name of year, place and animal*] *migration. This herd of* [*animal*], *estimated in 2013 to number around 1.3 million* [. . .]. *An estimate of the* [*animal*] *population is completed by counting the number of [animals] in a large number of images*."

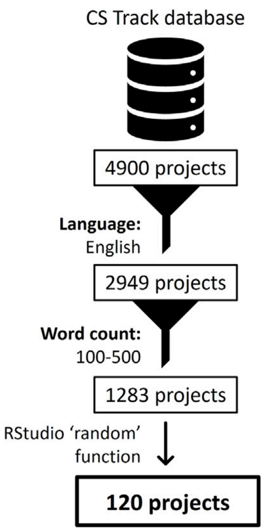


FIGURE 1
Diagram of the sample selection process.

## 3.2 Objectives and expected outcomes

Project goals were outlined in 96 of the descriptions in our sample (i.e., 84.2%) (Figure 4), yet only 31.5% met the criteria for a "good" project goal, as defined above. An example for a good project description is: "*The purpose of this project is to record the occurrence and location of* [*ecological phenomenon*] *throughout Europe*". A further 56 (or 58.3%) of project descriptions, did not present goals explicitly enough and were thus categorized as "fair." One example of a description that implies project goals without explicitly framing them as such, is the following: "*The* [*project*] *provides a harvest-independent index of grouse distribution and abundance during the critical breeding season in the spring.*" Another description states that "[*these activities*] *allow us to test fire mapping, interpret plant responses and assess changes to animal habitats.*" Yet another project informs the reader that "*These data will be used to create a snapshot of seabird density*".

In terms of goal subcategories (scientific, social and policy), scientific goals, such as collecting data, closing data gaps and answering research questions, were most commonly referred to (namely, in 82.5% of project descriptions coded as "good" in the category of goals). Both social goals related to public discussion, education and communication and policy-related goals were mentioned much more rarely, namely, in 25% and 22.5% of cases respectively (Figure 5).

Information about the project's impact appeared in nearly 50% (N = 56) of the project descriptions we analyzed. Of these, 33 projects (58.9% of those which indicated their impact) mention scientific impact and 32 (57.1%) were coded for policy-related impact. For instance, one project specified that they create tools "*that researchers all over the world can use to extract information*" (scientific impact), while another one stated their project conducts "*research that will ultimately help protect our fragile environment*" (environmental-policy impact), Social impact was referenced in 20 project descriptions (35.7%). One of these points out that data collected by their project are "*used in actions of environmental education*." Another project explains that its activities "*promote a process of awareness and self-reflection on the reality of people with mental health problems.*" While the impact statements are sometime vague, they remain important elements in the text, as they provide context for the projects' long-term contributions.

## 3.3 Method of operation

"Method of operation" refers to the inner workings or mechanics of a citizen science project, i.e., to the specific procedures and activities it uses to achieve its goals and engage participants. This includes the tasks participants are asked to complete in the project, the project's target audience, training and didactic resources offered to participants, and information on how to join the project.

Activities and tasks associated with participation in the respective citizen science project were mentioned in 83.3% of all project descriptions we studied (Figure 6). However, the majority of these texts (63.2%) contain only partial information on location, date, tools and equipment, or required time commitment. Examples for incomplete descriptions of activities and tasks (which were coded as "fair") include: "*submit your observations*", with no specification of the nature or location of the observations, "*transcribe information from the specimen labels*", with no refence to the technology used or time commitment, and "*tracking a tree's growth*", with no explanation on what this task entails. On the other hand, nearly one third of the descriptions we analyzed were coded as "good" because they contained detailed and informative explanations of the project activities. One project, for example, summarized the citizen scientists' tasks as follows: "*Using [app and website]: Stop 3–5 times along a pre-determined route and spend 5 min at each spot photographing/recording every insect that you see.*" This example detailed the technology used (name of platform), location (along a pre-determined route) time investment (5 min * 3–5 times), and detailed task (photographing/recording every insect). In another project the activity was described as: "*Participants register the nest boxes in their gardens or local areas and record what's inside at regular intervals during the breeding season*," indicating location (gardens or local areas), task (record what's inside their nest boxes) and timing and duration (regular intervals during the breeding season).

In terms of target audience, more than half of the descriptions in our sample (57%) failed to make any reference to the projects' intended audience. 17.5% contained vague or superficial statements (e.g., "*anyone in NSW*" or "*distributed global players*"). Only 25.4% mentioned specific groups, equipment needed in order to join or required skills. One project, for instance, is explicitly geared towards "*people who go on regular beach walks, boat trips, or scuba dives*", another project description informs readers that "*Absolutely anyone can join this project—all you need is an internet connection and plenty of free time!*".

Training processes and educational resources offered to citizen scientists were only referred to in 24.6% of the descriptions in our sample. Frequently mentioned types of training or instructions include downloadable guides, information sheets or video tutorials. A handful of project descriptions talked about in-person training or lesson plans for teachers.

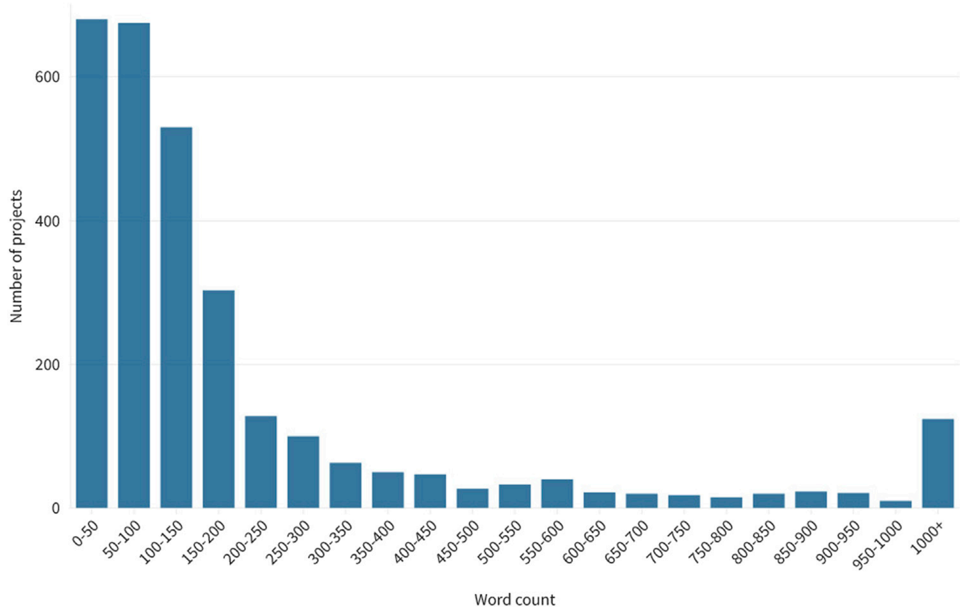


FIGURE 2
Distribution of English language project descriptions from the CS Track database according to their word count.

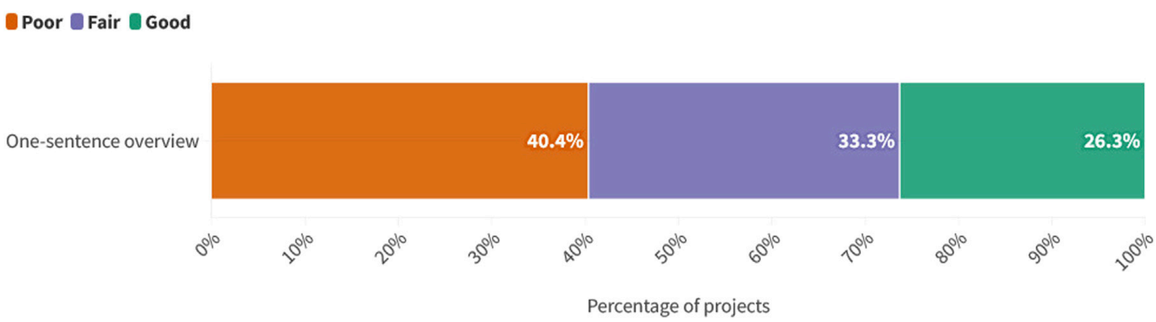


FIGURE 3
Percentage of projects descriptions coded as "poor," "fair" or "good" in the category "one-sentence overview."

Concrete, practical information on how to join the respective projects was only provided in 50% of the cases we analyzed. Typically, prospective participants are asked to "to sign up," "Create a free account," "download the mobile app" or "Click on the "Get Started" button." In some cases, they can directly "upload [their] observations" or "submit [their] data." A handful of projects require registration via email.

## 3.4 Volunteer and community management

Volunteer and community management refers to the processes and strategies used to effectively engage, recruit, and retain volunteers and community members who are involved in a citizen science project. On the level of project descriptions, this includes explaining which benefits participation will have for those who decide to join the project, whether they will have access to project outcomes and findings, and how their contributions will be honored and recognized. This dimension was remarkably underrepresented in the project descriptions analyzed, with 79 project descriptions ignoring it completely.

A mere 15.8% of project descriptions contained information on how volunteers can benefit from participating in the project (Figure 7). In the vast majority of those cases, the benefits mentioned are related to learning, i.e., to acquiring new skills and knowledge. For example, one project provides participants with "*new ideas for attracting wildlife to your backyard and community*." Another project offers a "*fun way for young people and other members of the public to learn alongside experts*". In a few cases, learning was associated with citizen scientists' health and safety - like in the project that "*...has helped waterfront residents[...] learn what makes for safer oysters and clams*" or the one where participants "*learn more about the*

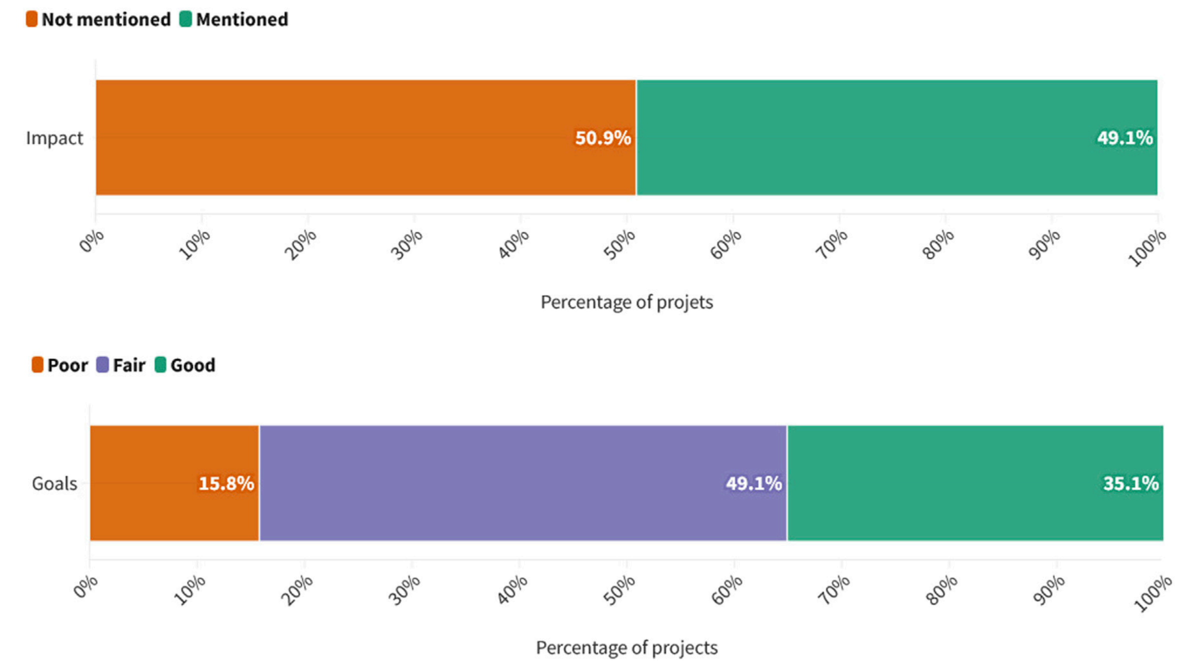


FIGURE 4
Percentage of project descriptions coded as "poor," "fair" or "good" in the category of "goals" (top) and as "not mentioned" or "mentioned" in the category of "impact" (bottom).

*existing resources for disaster and crisis management in their surrounding.*"

Similarly to the underrepresentation of participant benefits, only a small number of project descriptions (17.5%) detailed how participants may be able to access project outputs. Most cases which do describe access to data indicate that datasets and results are available for viewing or download on some form of website. One project description mentions that, after the end of the project, participants "*will receive a research report summarizing the results and findings of the whole project.*"

Finally, a paltry 6.1% of project descriptions contain details on how the contributions of citizen scientists will be acknowledged and recognized. Examples include being "listed as the collector" of a specimen displayed in a public exhibition or earning credit in the platform dashboard. A handful of project descriptions include expressions of gratitude, such as "*Thank you to everyone who helped us transcribe the slides*", or of appreciation, e.g., "*[the project] believes that the citizens of coastal communities are essential scientific partners*".

In summary, of the three project dimensions identified above (objectives and expected outcomes, method of operation, and volunteer and community management), the one discussed most prominently in the project descriptions in our sample was the first. Although impact is significantly less represented than goals, jointly this dimension has an average omission rate of just 33.4%. At 48.9%, the average omission rate of the second dimension, methods of operation, is significantly higher, which indicates that many project coordinators do not devote much attention to the practical or technical aspects of their project's day-to-day workings when writing project descriptions. Finally, volunteer and community management clearly is the most underrepresented dimension of the three, with an average not-mentioned rate across all categories of 86.9%.

## 4 Discussion

This paper aims to assess the quality and comprehensiveness of citizen science project descriptions found on online platforms. Our analysis focused on several key aspects of project descriptions, including an overview of the project, its purpose and expected outcomes, the level of detail provided about projects' methods and operation and about its approach to volunteer and community management. Through a systematic review of a sample of citizen science project descriptions, we identify areas for improvement and provide recommendations for enhancing the effectiveness and impact of citizen science initiatives.

We found that citizen science project descriptions vary greatly in terms of their content, length and style. In fact, over 50% of project descriptions in the CS Track database did not even meet our inclusion criteria, in terms of their length. Approximately half of the project descriptions stored in the CS Track database contain less than 100 words, meaning that key information on the project such as technology used, tasks to be completed and benefits of participation is inevitably lacking. Other project descriptions are extremely long with over 1,000 words and provide extensive detail and scientific background which may be difficult for participants to follow

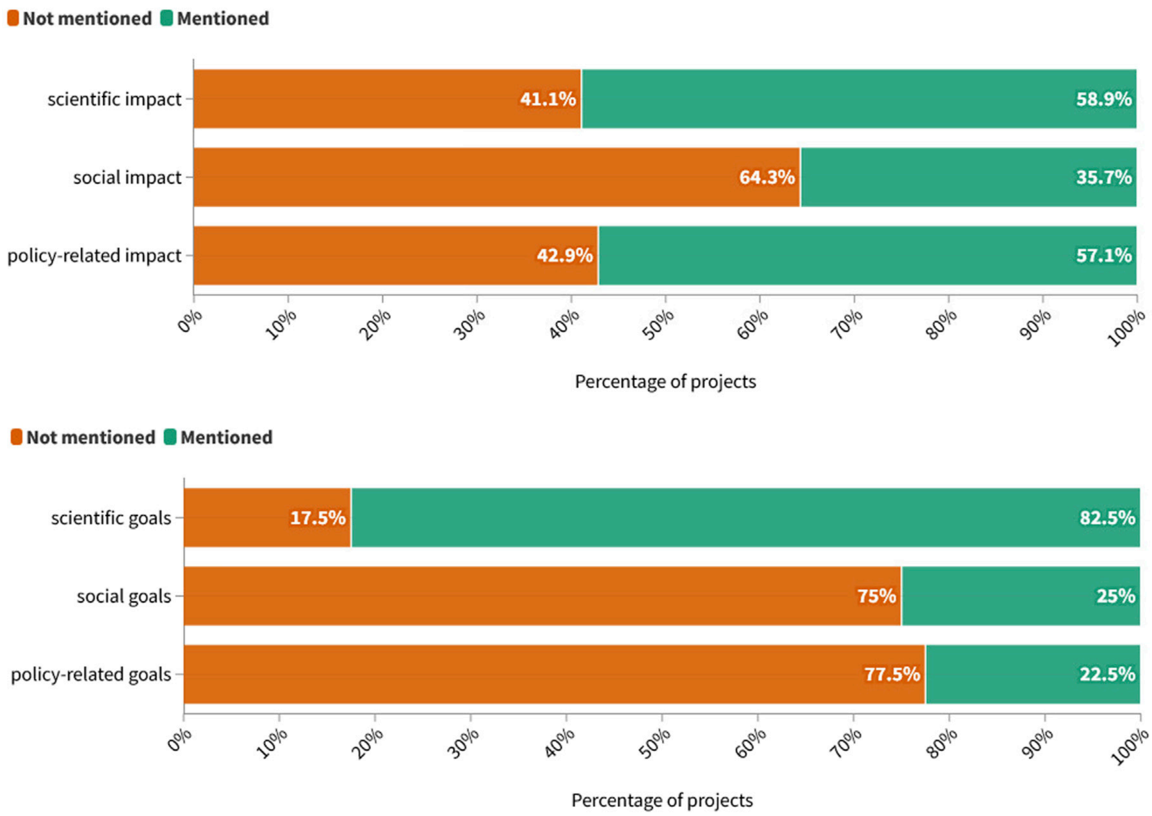


FIGURE 5
Breakdown of the types of goals (top) and impact (bottom) indicated by project descriptions. % are of those descriptions coded as "good" in the category of goals and "mentioned" in the category of impact.

(Meinecke, 2021). One notable observation from the analysis is that the style of writing in many project descriptions tends to be overly academic. Even among project descriptions with an appropriate word count (100–500 words), we found descriptions which provided lengthy and excessively technical explanations of the project's background and scientific context that make the text difficult for non-experts to understand. Overall, the style of writing was often more suited to an academic abstract than to a project description targeted at a general audience. This may be attributable to the fact that the majority of citizen science project coordinators and leaders come from a scientific background and have experience writing for such an audience. Yet, writing for non-scientists demands a different skill and style, which many scientists are not trained for (Salita, 2015). Popular science writing begins with the most important issue up front, followed by the scientific background and other technical details (Rabe and Vaughn, 2008). Yet, instead of opening with a succinct overview of the project, the descriptions we analyzed tended to start by providing background information on the field of study, describing the state of the art and identifying a research gap. As a result, the participatory dimension and the roles of citizen scientists in the project are only briefly mentioned towards the end of the description (or in some cases not at all). While this structure is perfectly appropriate for an academic abstract, it is not well-suited to capturing the attention of non-academic readers and motivating them to join. This is quite unfortunate since project descriptions are often the first point of contact between a citizen science project and prospective participants and thus play a crucial role in recruiting volunteers.

Our findings further demonstrate that of the three dimensions of project descriptions, the first dimension, purpose and expected outcomes, received the most attention. While goals were not always explicit, they were present in 84.2% of project descriptions, with the majority of goals being of a scientific nature. Mentions of impact, on the other hand, were spread more evenly across scientific, policy and social aspects. The comparatively strong presence of these elements within project descriptions suggests that project leaders view them as important elements of project communication. Alternatively, this could be derived from the academic style writing which includes an emphasis on the goal of the study alongside its contribution for research and practice (Bray et al., 2012).

The second dimension, which encompasses the methods and operations of projects, featured much less prominently, meaning that the practical and technical aspects of day-to-day participant engagement were not sufficiently emphasized in project descriptions. This finding raises questions about the extent to which project coordinators are effectively conveying the operational aspects that contribute to participant engagement and

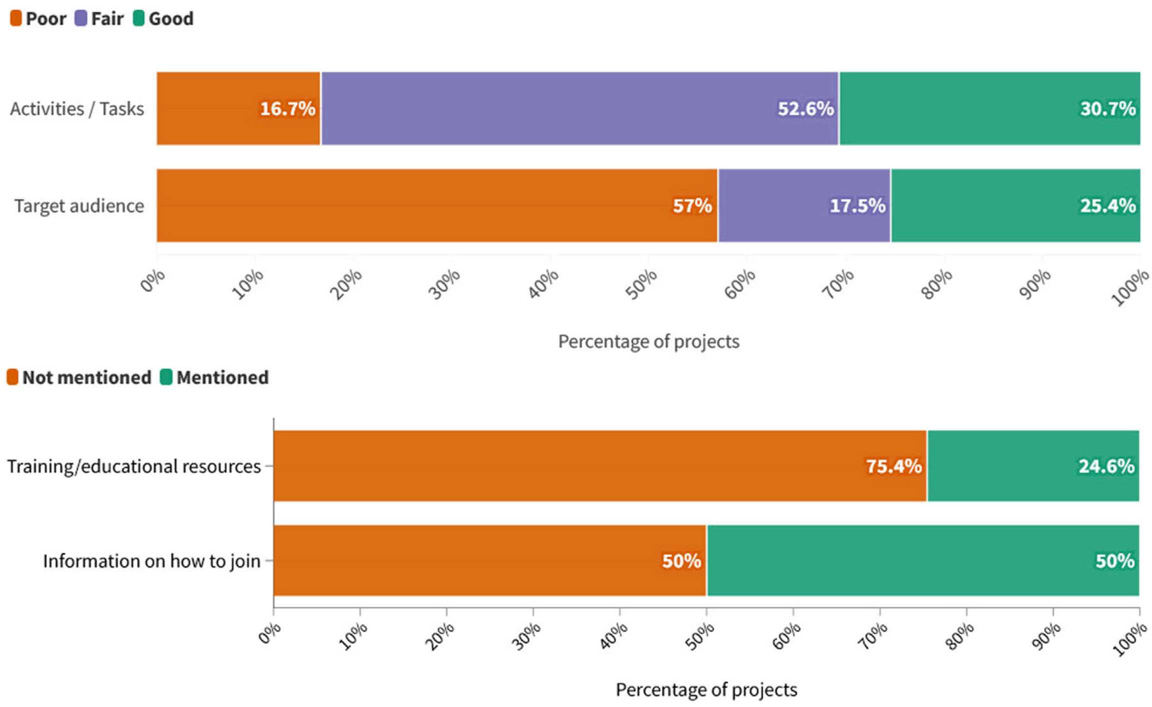


FIGURE 6
Percentage of project descriptions coded as "poor," "fair" or "good" in the categories of "activities/tasks" and "target audience" (top) and as "not mentioned" or "mentioned" in the categories "training & educational materials" and "information on how to join" (bottom).

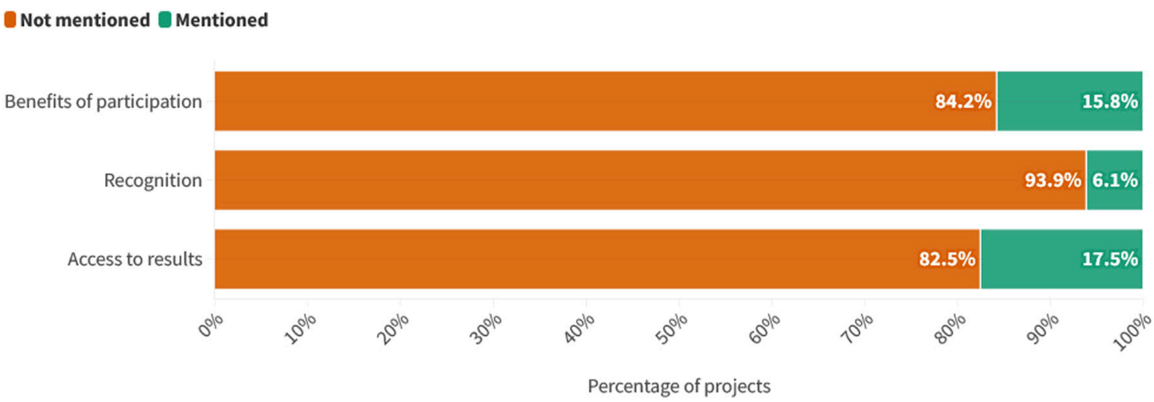


FIGURE 7
Percentage of projects descriptions coded as "not mentioned" or "mentioned" in the categories "benefits of participation," "recognition for citizen scientists" and "access to results."

project success. If potential participants do not understand the tasks they are asked to complete, or who the project is targeting, they are less likely to join the project as participants (West and Pateman, 2016; Hart et al., 2022).

The third dimension, volunteer and community management, emerges as the most underrepresented aspect across all categories, with an overwhelmingly high omission rate for all three elements (benefits, recognition and access to results). It is evident that project descriptions often fail to address the crucial role of volunteers and the management strategies implemented to support community involvement. This highlights the absence of a participant-oriented approach to project management as reflected by project descriptions. As volunteer support, recognition and community engagement are vital for the success and sustainability of citizen science projects (de Vries et al., 2019; Asingizwe et al., 2020), it is crucial that these are adequately reflected within project descriptions.

## 4.1 Writing effective project descriptions

As discussed above, a significant portion of the project descriptions we analyzed were written in the format of a paper or conference abstract. Stylistic conventions typical of academic writing make the text less attractive for non-scientist audiences and may also be to blame for the rather indirect or implicit way project descriptions present information. Often, the clarity and accessibility of a project description could be improved significantly by applying the following three principles:

1. ***Explicitly mention your project and what it will do***—make sure the project is the subject of your sentence and avoid writing in a way that leaves the reader to guess the connections between the project and its activities. For example, rather than writing: "*In order to be able to make better predictions about future climate change, scientists need to know more about how decomposition occurs*," make the project and its activities more visible by stating: "*By collecting data about decomposition, this project will help scientists make better predictions about future climate change*". Whilst the change in style may seem trivial to some readers, others will find the second version more accessible and clear, as it does not expect them to infer that the project will provide information scientists need.
2. ***Avoid the passive voice***–mention the persons or teams conducting the research and write your message directly to your reader. Writing in the active voice will help you highlight and acknowledge the work scientists and citizen scientists are doing in the project. It will also make it easier for you to explicitly state which activities participants will be engaging in. For instance, instead of writing "*Through this project, ten thousands of documents will be annotated and made available to interested researchers and members of the public*" you could inform the reader that "*Together with the project team, you—our volunteers—will annotate ten thousands of documents, making them available to interested researchers and members of the public.*" As this example shows, a simple change in syntax affects both the tone of a sentence and the message it conveys.

3. ***Be brief and to the point***—Do not include an excess of information, particularly regarding technical aspects or the scientific background of the project. Try to find the right balance between providing all the information prospective participants may need, while not overwhelming them with too many details. For example, "*This project looks at the seasonal migration patterns of two bird species—black storks and common cranes*" is much easier to understand than the much more detailed version: "*This project looks at the seasonal migration patterns of the black stork (Ciconia nigra, native to Portugal, Spain, and certain parts of Central and Eastern Europe, migrates to sub-Saharan Africa) and the common crane (Grus grus or Eurasian crane, mainly found in Eastern Europe and Siberia, migrates to the Iberian Peninsula and northern Africa)*". While the additional pieces of information included in the latter version may be relevant in the project context, they hamper the comprehensibility of the text and are in all likelihood not pertinent to the readers' decision on whether they would like to join the project or not.

Additional recommendation for writing project descriptions alongside advice on style and format, can be found in the project description template this study was inspired by (Golumbic and Oesterheld, 2022). Furthermore, some online tools exist for supporting writers in improving the readability of their texts for lay audiences. Examples include the De-Jargonizer[1], a free online tool developed by Rakedzon et al. (2017) which identifies overly technical words, jargon and complex phrases in the text, or the Hemingway Editor App[2] which highlights lengthy, complex sentences, common errors and uses of the passive voice. These tools have been tested with students and shown to enhance their writing skills and improve the reader-friendliness and accessibility of texts (Capers et al., 2022; Imran, 2022).

## 4.2 Study limitations and future research

While this study aimed to utilize a representative sample of citizen science project descriptions, a number of limitations influence the results and interpretations. First, as the analysis was conducted in English, all projects presented in other languages have inevitably been excluded from the analysis. The results of this study therefore may not pertain to non-English platforms. Additionally, since the CS Track database contains information on citizen science projects extracted from a wide range of platforms, differences may occur in the way project descriptions are presented, which in turn influenced our analysis.

On some platforms, for example, information on the project is spread across several tabs, like in the case of Zooniverse which has a landing page, and an "About" section consisting of five tabs - Research, The Team, Results, Education, and FAQ. In these cases, and for reasons unknown, the web crawler sometimes extracted text only from one or two tabs leaving out crucial information. While we excluded any descriptions that were evidently disjointed (i.e., not part of a coherent running text or narrative), we decided against manually correcting these crawler errors since doing so would further bias our sample and in many cases have resulted in a project description exceeding our word limit. SciStarter, which accounts for 60% of the texts in our sample, asks project coordinators, to fill in a form containing both text fields (e.g., "goals," "tasks" and "description") and drop-down menus (e.g., "average time," "ideal frequency"), in addition to submitting a full project description. As a result, project pages on SciStarter usually contain both structured and unstructured information. The CS Track web crawler mainly extracted the unstructured information (i.e., the running text contained in the "description" field), meaning the information added in the platforms' pre-defined fields is sometimes absent in our sample. On iNaturalist (which constitutes 3.3% of our sample) all observations submitted by citizen

1 De-Jargonizer, Available online at: https://scienceandpublic.com (accessed 23 May 2023).

2 Hemingway Editor, Available online at: https://hemingwayapp.com (accessed 23 May 2023).

scientists are by default visible and accessible on this platform. Accordingly, project coordinators may not see any reason to include information about "access to results" in their descriptions.

However, while limitations of the web crawler and the structure and characteristics of the platforms themselves have inevitably influenced the results of our analysis, the main argument presented in this paper still holds. Vital pieces of information about a citizen science project should always be included in the project description itself, even if they are also written elsewhere—in other tabs or structured sections of the platform. Otherwise, website visitors are forced to click and/or scroll through several pages to find the information they seek. Some readers may not be willing to invest the time and effort needed and instead simply move on to the next project.

We also acknowledge that while this analysis was based on literature and expert experience and validation, it did not incorporate perceptions of prospective audiences. Future work could examine how non-expert readers perceive and interpret texts. One option would be to present such readers with a selection of texts written in different formats, styles and speech registers, and ask them to assess their attractiveness, clarity and fitness for purpose.

## 5 Conclusion

Citizen science is growing dramatically, engaging thousands of volunteers who contribute daily to a wide range of initiatives, from health to astronomy and biodiversity. As citizen science continues to establish itself as an independent field of study, the pivotal role of science communication becomes increasingly evident. Yet, our analysis reveals that many citizen science project leaders or coordinators fail to incorporate science communication practices when writing project descriptions. Many project descriptions are structured like an academic abstract and do not sufficiently address practical matters of project participation and aspects related to volunteer and community management. These findings highlight a much bigger challenge of citizen science, namely, inclusion and diversity. In other words, project descriptions written in an academic style of writing contribute to the problem of homophily in citizen science—they are more likely to attract participants with university degrees and high science literacy, rather than people with different educational and linguistic backgrounds or abilities. Our findings underscore the need for project coordinators to adopt a more holistic approach, that takes into account all of the project dimensions identified in our rubric, including those related to volunteer support, recognition and community engagement. To ensure readability, project descriptions should be explicit, written in an active voice and include only vital information. Following these guidelines will help project coordinators compose comprehensive, readable and engaging project descriptions and streamline the communication with potential volunteers. Engaging project descriptions will spark the readers' curiosity, foster a deeper interest in the project's objectives and encourage their active involvement.

## Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

## Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

## Author contributions

YG and MO both led the conceptual design of the manuscript, conducted the data collection and analysis, developed the coding rubric, created images and wrote the manuscript. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1228480/full#supplementary-material

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# Branding the MEGA lab; methods to improve science communication and citizen science engagement

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The MEGA Lab uses branding and marketing techniques as a complementary form of science communication to improve citizen science. Storytelling, inclusivity, personalization, digital marketing, and collaborations are key components to brand marketing. Through branding, science projects within the MEGA Lab have increased their visibility, attracted more participants, and enhanced credibility. In addition, the MEGA Lab branding can also help citizen science projects to reach a wider audience. By promoting the MEGA Lab brand through social media, outreach events, and other channels, citizen science projects can increase inclusivity by attracting more participants who are interested in contributing to scientific research. We believe that other science research programs and citizen science projects can benefit from branding as a complementary form of science communication. By improving science communication, it is proposed that targeted citizen science projects can improve their visibility, credibility, and impact. This can lead to more effective and valuable contributions to scientific research, as well as a greater understanding and appreciation of science among the general public.

KEYWORDS

**MEGA lab, science branding, SciComm, citizen science, science communication, science marketing**

## Introduction

We cannot do it alone. Science that is. More specifically, we scientists cannot do our research without funding, equipment, infrastructure and perhaps most importantly, data. As society rapidly sprints towards the 22nd century, data acquisition methods are becoming increasingly diverse especially within the environmental sector. Citizen science (CS), the intentional contribution of data by non-formally trained scientists, presents a highly innovative and practical form of data capture and processing (Silvertown, 2009; Tulloch et al., 2013; Bonney et al., 2014; Theobald et al., 2015; Bonney et al., 2016; Iyengar and Massey, 2019). Like the latest mass spectrometer or a genome visualization program, CS joins the chat as a potentially low cost, highly impactful and data rich source for making new discoveries.

CS has already proven to be highly impactful in the fields of ecology, astronomy, microbiology and social science with projects ranging from simple observations and data collection to more complex experiments and analyses (Dickinson et al., 2012; Marshall et al., 2015; Palmer et al., 2017; Pocock et al., 2017; Tauginienė et al., 2020). So if CS is so valuable, why is not it included into more research methodologies? Some limitations of CS that may have researchers slow to adopt include concerns around data quality, bias, resources, ethics, and also participation (Bubela et al., 2009; Robinson et al., 2021; West et al., 2021; Fritz et al., 2022; Hart et al., 2022; Hart et al., 2022; Hart et al., 2022). Since citizen scientists may not have conventional training, human error may dramatically increase during data collection if quality control methods are not implemented (Wiggins et al., 2011; Kosmala et al., 2016; Downs et al., 2021). CS can often bias towards certain populations that misrepresent data (Pandya, 2012). For example, more data may be acquired if methods are biased towards cell phone usage, which in turn will bias CS data towards individuals with access to cellular technology. The resources of CS are often heavily reliant on volunteer infrastructure and technical support. Budgetary restrictions may serve as an entry barrier for researchers to involve themselves in CS. The ethics or considerations that address privacy, confidentiality and informed consent can also hinder researchers from implementing CS into their research workflow (Angrist, 2009; Resnik et al., 2015; Rothstein et al., 2015). One of the fundamental pillars of CS is the need for volunteer participation. This often relies on the willingness and availability of volunteers to engage in a research topic. A significant bottleneck to CS effectiveness is the difficulties of attracting and retaining volunteers (Dickinson et al., 2010; Kobori et al., 2016; Brouwer and Hessels, 2019; Liñán, 2022, 2023).

Despite the drawbacks of CS in science research today, there is a consensus among many across the science community that obtaining more data has great benefit for any research program. And by increasing diverse and inclusive methods of CS participation, research programs can elevate their potential for scientific impact beyond academia alone and into the general public. Although there are many different methods that can elevate CS participation through incentives (Aceves-Bueno et al., 2015; See et al., 2016; Weber et al., 2019), improving accessibility (Roger et al., 2019; King et al., 2020; Roche et al., 2020), collaboration (Rotman et al., 2012; Kaufman et al., 2017; Guerrini et al., 2018), gamification (Bowser et al., 2013; 2014; Eveleigh et al., 2013), and science communication (Hecker, 2018; Batsaikhan et al., 2020), here we propose a underutilized method, branding and marketing techniques as a complementary form of science communication to improve citizen science.

## Branding and marketing science communication

In particular, science communication can lead to increased participation in CS (Holliman et al., 2009; Luís et al., 2022). Science communication focuses on sharing scientific ideas, concepts and results to broader audiences both in and out of the scientific community (Burns et al., 2003; Bubela et al., 2009; Fischhoff, 2013). Different mediums of science communication can be implored such as written, oral, visual, digital, phonetic, and sensoratory (Fischhoff, 2013). Effective science communication methods raise awareness by providing greater accessibility, engagement, storytelling and outreach than most traditional scientific publications. An emerging method of science communication comes in the form of sharing a scientific story, idea or objective as if it were a brand (Maclachlan, 2016; Hotez, 2018).

By developing strong research narratives that highlight organization and identity, research programs can leverage the power of brand marketing. Storytelling, inclusivity, personalization, digital marketing, and collaborations are key components to brand marketing (Herskovitz and Crystal, 2010; Kannan and Li, 2017; Chandra et al., 2022; Ibáñez-Sánchez et al., 2022; Lucarelli, 2022). Storytelling techniques allow for science concepts to be more relatable to a broader audience. Using narratives, characters, emotions and places, researchers can form connections between science and an individual's interest. By illustrating that scientific participants come from different backgrounds, it promotes a message of inclusivity and diversity for individuals to feel safe in a scientific setting. Personalization is important in the targeting of a specific audience based on interests, behavior and demographics. When messaging is tailored to different groups of people, engagement and relevance among audiences can increase. Digital marketing utilizes multimedia channels such as social media, search engines, and email marketing to broaden the reach of a particular campaign or narrative. Data analytics, also known as key performance indicators such as following, subscribers, views, shares, likes and impressions can support researchers in discovering what methods of communication are most effective when engaging new audiences. Collaborations with corporate organizations, influencers and celebrities can increase the reach of a particular scientific message or narrative further diversifying broader audience capture.

## The MEGA lab

The multiscale environmental graphical analysis (MEGA) lab is a Hawaii based research group that specializes in producing novel scientific research while broadening the aperture for scientific participation (Figure 1). The lab initiated as an interdisciplinary and interinstitutional research group led by faculty at the University of Hawaiʻi at Hilo, University of Hawaiʻi at Mānoa, and Arizona State University and has also established an independent non-profit organization to expand its capacity to connect with broad audiences. The mission of MEGA Lab is to develop new technology to improve ocean research and provide that technology to communities who may need it the most. The lab includes five academic professors, three tenured-track, one research and one associate professor, three PhD students, four masters students, ten undergraduate students, an event space builder, and two multimedia creators.

### Examples of branding and marketing used by the MEGA lab

In the brand development of MEGA Lab, storytelling plays a vital role (Figure 2). Developing a strong brand narrative can heavily influence the rest of the brand marketing strategy. The lab aims to change the way people experience science by showcasing that individuals from diverse backgrounds can use science to create innovative solutions to protect the planet. The lab specializes in

FIGURE 1
Previously an early-century furniture store, the MEGA Lab now occupies the second floor of the Mokupapapa Marine Discovery Center. Open to the public at no cost, it provides opportunities for visitors to engage in scientific observation, communication, and exploration.

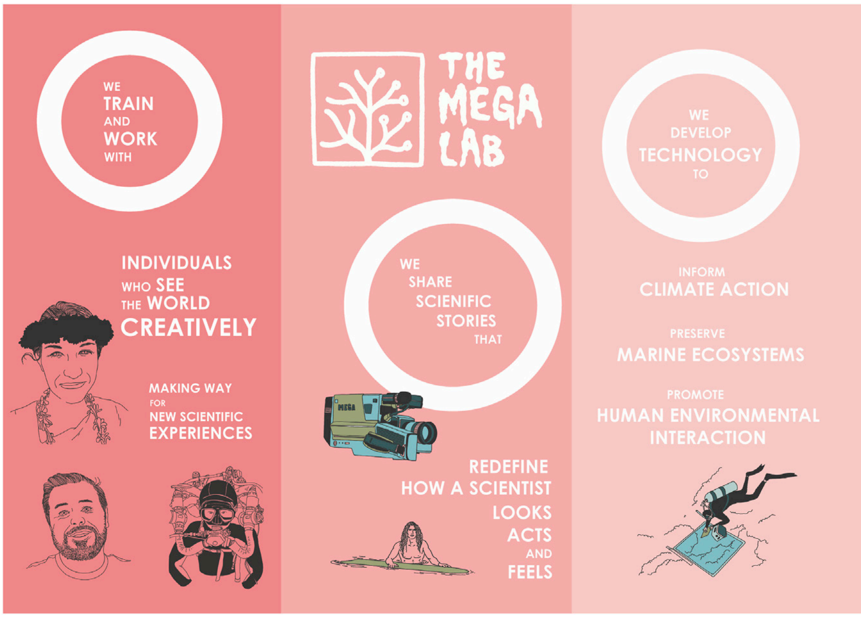


FIGURE 2
The Multiscale Environmental Graphical Analysis (MEGA) Lab focuses on scientific training, communication, and research through the use of multimedia, branding and original artworks.

ocean research, with storytelling focused upon projects related to the changing climate, marine ecosystems, and the interactions between humans and the environment. To achieve its goals, MEGA Lab supports, trains, and partners with creative individuals to develop new ways to protect the planet and the communities that inhabit it. By emphasizing storytelling in brand development, MEGA Lab can communicate the importance of science in protecting the planet to a broader audience and inspire more people to take action.

For example, MEGA Lab prioritizes inclusivity and personalization by utilizing a key storytelling element that surfers, skaters, and artists can protect the planet. Members of the surf, skate and art community are often creative, passionate and dedicated to their discipline. Moreover, these seemingly distinct areas frequently intersect, creating interdisciplinary connections that extend across the boundaries of land and sea, as well as indoor and outdoor environments. Although the similarities among creatives demonstrate strong potentials towards developing solutions towards complex environmental disturbances, many surfers, skaters and artists do not see themselves as scientists or receive scientific encouragement. The MEGA Lab recognizes the potential of these individuals and seeks to provide conventional scientific training to them. With opportunities in scientific research that focus on environmental issues, MEGA Lab is using CS to target groups that possess unique perspectives and deliver fresh approaches that traditional scientists may not have considered. MEGA Lab demonstrates through CS, research and training that science is for everyone, even those who do not traditionally consider themselves scientifically literate.

MEGA Lab branding is shared through various digital platforms such as social media, original short films, photography, filmmaking, and podcasts to reach wider audiences and share its message. By developing different content specifically for different applications, MEGA Lab is able to tailor its messaging to specific audiences and channels.The lab also partners with news outlets, radio, and surf skate and art publications to share its message.

In addition to developing original content around the MEGA Lab's mission, we have created an underwater livestream camera that provides audiences online with 24 h surveillance of the reef. Using online metrics we are able to quantify public engagement including citizen scientists. Since its establishment in 2021, there are currently 10,700 viewers have subscribed resulting in over 1.5 million views and over 700,000 h of watch time. Average watch time of the live stream is approximately 27 min each day. A majority of audiences are based in the US (71.6%), and the remaining audiences are from Canada (4.2%), the United Kingdom (3.8%), Japan (3.0%), German (1.8%), Brazil (1.6%), Russia (0.9%), Australia (0.7%), India (0.6%), France (0.6%), Netherlands (0.4%), Italy (0.4%), Spain (0.3%), Mexico (0.3%), Taiwan (0.3%), Poland (0.2%), Aotearoa (0.2%), Indonesia (0.2%), Argentina (0.1%), Sweden (0.1%), Austria (0.1%), Denmark (0.1%), South Africa (0.1%), South Korea (0.1%), Ukraine (0.1%), and Finland (0.1%). Interestingly, a majority of these viewers are between the ages of 55–64 (28.1%) and are male (57.3%). While viewing the live stream, audiences transitioned from being passive viewers to CS themselves as they began voluntarily commenting on marine species identification without a prompt. This has led to new datasets that highlight never before seen behavior and presence of marine life on Hawaii Island.

The MEGA Lab believes in the importance of traditional and non traditional partnerships when executing brand strategy. Although non-traditional forms of collaboration are important to the values and ethos of MEGA Lab, members of the broader scientific community still need to see that MEGA Lab is a successful research lab that has the capacity to gain support from national endowments or granting agencies. That being said, MEGA Lab invests time and resources into national partnerships that stem from successful grant opportunities from the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), the United States Fish and Wildlife Service (USFWS), the Department of Defense (DOD), the National Park Service (NPS) and Burroughs Wellcome Fund. MEGA Lab also collaborates with organizations and corporations that align with its messaging. For example, the MEGA Lab has a multi-year partnership with REEF footwear as a corporate collaborator to mutually elevate conversations around reef conservation, research and protection. REEF supports three main pillars of MEGA Lab's work by investing in MEGA Lab scientist's ability to maintain professional surfing status, supporting MEGA Cam live stream marketing efforts, and most notably partnering with MEGA Lab to perform original research destined for peer-review. As far as we are aware at the time of this publication REEF is the first surf company to invest this way into a research lab. In partnership with REEF, over 100,000 individuals have viewed the MEGA Cam livestream (https://themegalab.org/livestream) and we have mapped over 20,000 $ft^2$ of reef at some of the best surf breaks around the world.


FIGURE 3
Working closely with industry partners such as Reef footwear to develop branded content, the MEGA Lab has created a branding niche that is widely celebrated within the surf industry.

The MEGA Lab - REEF partnership has become a model relationship that demonstrates the feasibility and scalability for corporate partners in the outdoor recreation space to invest into science research to increase ocean protection and awareness (Figure 3). A recent trip to a famous surfing destination Nakurukurumailangi, Fiji also known as Cloudbreak, was funded primarily by REEF footwear to characterize the reef ecosystem. In addition to the data collected, REEF invested into a marketing campaign and media partnerships that introduced the broader surf community to the concept of indigenous research and marine photogrammetry. A 20-min documentary campaign was also created and accepted into several film festivals eventually finding a distribution home on both Surfline and Outside TV's Dispatches program garnering over 340,000 views to date.

Since its release the "Mapping the Reef: Cloudbreak" research project has reached over 30 million impressions across multiple online platforms, over 1,000 in person, provided research training for 6 graduate students and a forthcoming research paper is currently in preparation. The project has also been celebrated in several news and entertainment periodicals including The Fiji Times, Hilo Union Tribune, Wavelength Surf Magazine, KHON2 News, ASU News, and UH News. As a result, the MEGA Lab was awarded an impact grant by the World Surf League, the governing body of professional surfing. With partnerships from GoPro camera systems, this grant will be used to create do it yourself, "DIY," mapping kits that will be used next year to map the reefs on the North Shore of Hawaii by visiting athletes and local community members.

## Conclusion

The effort required to invest into market branding for both a research program and project can be overwhelming. At times it might also seem tangential to the trajectory many researchers believe their career must take them. Although including brand marketing into science research strategy is less common, this underutilized tool certainly has complementary value to traditional methods of science communication. Challenges still exist within the research community as to whether these methods deem valuable and align with overall research goals. Additionally, evaluation metrics to determine effectiveness remain unclear. The data that the MEGA lab focuses on in this perspective piece, is the media engagement metrics and subscription following across social media. For example, the MEGA cam live stream has provided access to ocean observation and engagement to over 25 countries around the world with a base audience of at least 10 people in each location. From these live streams, active engagement of audiences in the chat and comment section resulting in over 220,000 comments that describe animal presence, behavior and even absence.

The overall goal of this piece is to propose an alternative and seemingly effective means of branding a lab through the use of digital marketing. Although an extensive evaluation of the effectiveness has not been established in this paper, the authors propose a unique branding structure that results in active engagements of non-science users across the digital space. As demonstrated by the MEGA Lab, operating in the space of branding can lead to increased opportunities for involving citizen scientists where we have never looked before. Future efforts of the MEGA lab will include the exploration into the effectiveness of broader community engagement through live events, ambassadorship collaborations, and incentivized subscriptions.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## Author contributions

CK conceived of the idea in discussion with HK and JB drafted the manuscript with support, input and edits from HK and JB. CK produced all figures. All authors contributed to the article and approved the submitted version.

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The MEGA Lab partners closely with the Mokupapa Marine Discovery Center and is a major supporter of public engagement. MEGA Lab also partners with Reef Footwear and Hydro Flask water bottles to provide scientific messaging to broader audiences.

## Conflict of interest

Authors CK, HK, and JB serve as board members of the MEGA Lab, but are not employed by the MEGA LAb.

## Publisher's note



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# Is there a role for citizen science in death and dying research?

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The COVID-19 pandemic has brought conversations about death and dying to the fore in a way not experienced for generations. This raises questions around perceptions of death and dying; the role of healthcare and the community in care; and the use of digital media for information and support. Public engagement can provoke a two-way conversation between researchers and the public and includes techniques that can engage the community not only with the topic but also in research. This perspective article considers the potential role of citizen science in death and dying research, including considerations around its potential benefits and constraints.

KEYWORDS

**hospice, death, dying, end-of-life care, public engagement, citizen science**

## 1. Introduction

Previous studies of death and dying, and the role of hospices and palliative care, have found understanding among the public is mixed, with women and older people more commonly aware of the role of hospices (1). Lack of understanding can result in hospice care and community support being difficult to navigate (2), with hospice care underutilized, leading to calls for increased education and engagement (3, 4). Early conversations about death and dying are helpful in providing care and preparing for loss (5) but can be challenging conversations to have (2, 6, 7). In previous research conducted in the UK >75% of participants had some awareness/understanding around the role of hospices, but only half of these had a conversation about planning for their end-of-life (8). End-of-life care is increasingly focusing beyond professional settings, to family and "compassionate communities," in promoting the wellbeing of dying, caring, and bereaved people (2, 9) therefore there may be increasing opportunities to engage and involve citizens in such conversations.

### 1.1. The role of public engagement

Death and dying are challenging and emotive subject areas, where there can be significant differences in understanding, alongside social, cultural, religious and spiritual variations. Public engagement has multiple definitions but is broadly understood to involve a two-way process, involving researchers and the public, which aspires to there being mutual benefit from the interaction (10).

Considerable research on death and dying has been conducted through traditional methods such as interviews and surveys (3), but these rarely include 'public deliberation, whereby people engage collectively with an issue, consider it from all sides, and struggle to understand it' (11). Challenges in public engagement around death and dying include resistance and lack of interest in planning ahead, a view that one is living rather than dying (even when experiencing significant or complex illness) and understanding how to demonstrate the relevance of the subject matter, beyond those experiencing death, dying or grief (12). Communicating relevance has become even more challenging when 'public engagement on end-of-life cannot compete with the vast array of more powerful messages relating to youth and health' (12).

Nevertheless, public engagement is increasing (13–17), including Death Cafes and festivals (18, 19) and via traditional (20), and social media (21). These engagement examples can be highly participatory in nature and build significantly on the lived experience. However, they also highlight the sensitivity of the subject, whereby differing opinions are common, and aspects of death and dying can be more challenging to discuss openly.

### 1.2. Citizen science

Citizen science is one of a vast array of public engagement methods now available to researchers and is broadly seen to be both an opportunity for participants to contribute to the scientific process and to gain something in return (22). Citizen science projects actively involve citizens in research that generates new knowledge or understanding, as contributors, collaborators or as project leaders (23). While it has an extensive history in fields such as natural history, archeology, and astronomy, the tools of social and digital media have particularly increased citizen sciences expansion, though many of the methods it uses are akin to epistemic approaches used by social scientists for many years (24).

Citizen science has been described as a "cluster of activities" which can include approaches such as open science and open innovation, drawing in a multitude of information sources and disciplines [(25), p. 1], but it also has important ramifications for stakeholder and community engagement in 'building capacity for communities to participate in science and shape policy decision-making and implementation in the longer term' [(25), p. 1].

People participate in citizen science for multiple reasons. These include personal and altruistic motivations, having interest and support for project goals or a desire to contribute to research, learn and participate (26). Notably, a number of the most successful citizen science projects, such as Galaxy Zoo (27) have tended to attract more male participants, and there are arguments that citizen science could be more inclusive (28). From the perspective of research however, citizen science can provide opportunities for people to collect and add data, participate in data processing and analysis, shape research questions or contribute to writing up. In ideal circumstances, citizen science projects create mutual benefit to both researchers and citizens, as well to the research itself (29).

Citizen science requires considerable advanced planning. This includes considering how participatory an activity will be, how it can be conducted safely and ethically, how data quality can be ensured and how participants will be adequately recognized within the process (26, 28). As a result of its increasing use a number of frameworks and principles for citizen science now exist. In Europe, the Ten Principles of Citizen Science set out a shared view of the characteristics that underpin high-quality citizen science (23). While in the US the Code on Crowdsourcing and Citizen Science Act (30) outlines citizen science and how it can be used in federal settings.

Moves to develop increased protocols and quality measures for citizen science may help to assist the approach to develop beyond the most obvious opportunities for data gathering and manipulation (31). In light of the growth of citizen science there are also calls for improved definitions of citizen science, including what it is, what it is not, and what quality criteria projects should meet (32).

## 2. Citizen science in health and social science research

The emergence of citizen science has arguably favored a science framing, neglecting the significant potential it may have in other areas of research including patient and public involvement in health settings, and the potential of the technique for use within the social sciences.

To ascertain what is known about citizen science projects in these fields, we undertook a scoping review. Scoping reviews are helpful in determining whether a full systematic review is possible and aim to be transparent and systematic, but they do not operate with the same level of scope or assessment of quality (33). Two searches were conducted of the academic and grey literature in February 2020, including the terms "Citizen Science AND Health", "Citizen Science AND Social Science" with search results then filtered and assessed for relevance. In the case of citizen science and health, references to environmental health were excluded. Editorials, commentaries excluding original data or projects, and letters in response to articles, were also excluded in both searches. The searches identified 23 relevant items located in the health search, and 10 in the social sciences search, including one item that appeared in both searches (Figure 1). The wider study in which this scoping review was conducted did not focus on assisted dying as a subject area. This topic was not excluded from the scoping review search criteria.

### 2.1. Citizen science in health research

The 23 items located within the context of health had all been published since 2016, with the majority published since 2018 (See Supplementary Table S1). Articles focused on use of health technologies and their potential adaptation for citizen science type projects (34). Public health was a popular area for articles, including focuses on emergency preparedness (35), the built environment (36), urban and rural environments (37), as well as broader questions around building public health and medical research that is more inclusive (38, 39). There were synthesis and scoping studies on issues including data management (40), as well as articles which attempted to create frameworks or models of different types of citizen science (41).

Articles stressed the relevance of citizen science for gathering health related data, for example using smart phones to capture photos and audio narratives (36), building in short surveys (42), interviewing (43) and the creation of dedicated apps (44). Benefits for citizens involved included personal empowerment as well as knowledge, skills and social networks (43). Benefits also extended to the communication of end results as the public have already been involved (42) and demonstrated the role citizen science could play in direct policy interventions (44). This also translated to ongoing actions and

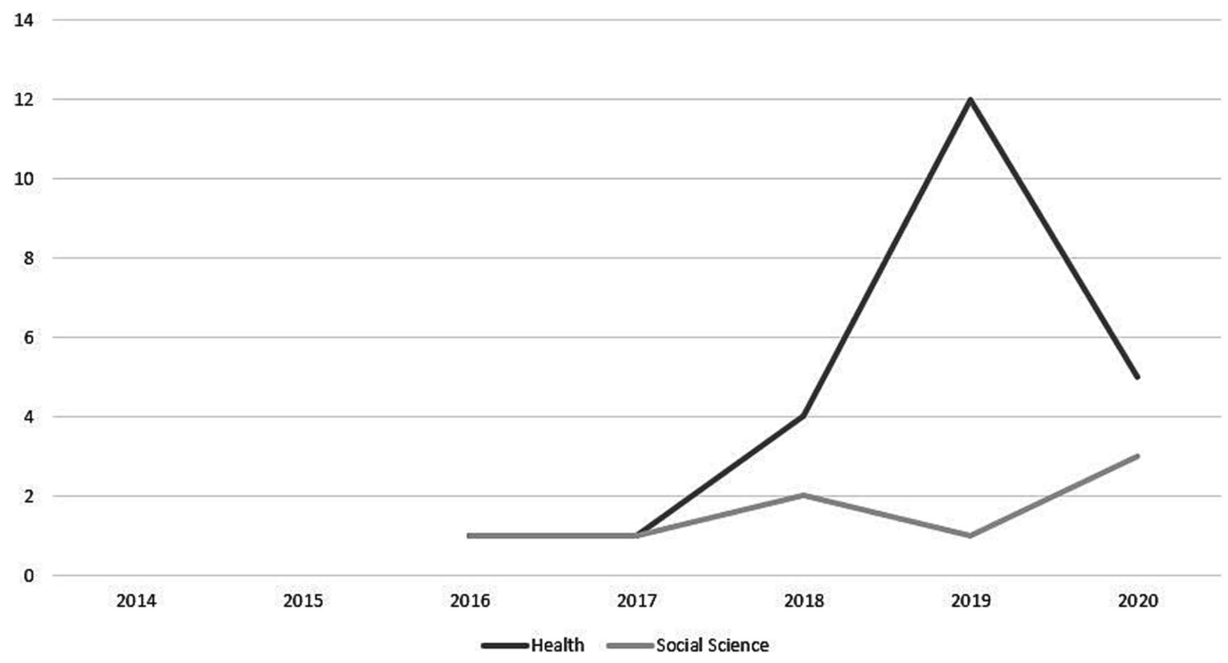


FIGURE 1
Articles by publication year.

behavior changes, for example a citizen science project which included the recording of physical activity, resulted in the formation of a regular walking group (45).

It was common to explore the ethical challenges surrounding both citizen science and the capturing of health information (25), including how citizen scientists should be supported in sharing data and publishing findings, and the types of norms and policies that are emerging and can be adapted to health contexts (46).

## 2.2. Citizen science in social science research

Ten articles of relevance (See Supplementary Table S2) had been published since 2014, with the majority of articles published since 2018. The articles focused on topics including methods for citizen science, ethics, benefits and constraints, and use in specific disciplines such as computational science and workplace learning.

Articles discussed how citizen science can be amenable to the observation of everyday life, and therefore particularly responsive to the interests of social science and humanities researchers (47, 48). For example, observation of people requesting money on the street (49) or "pop up experiments" in urban settings (50), including approaches which are interdisciplinary (51). One article discussed the benefits for behavioral studies where lab-based experimental protocols have limitations (52). A further study endorsed the use of citizen science in workplace learning, in this case working with clinicians to gather data (53). Examples also discussed the relationship between citizen science as one form of participatory approach and behavior change, for example around environmental behaviors and climate change (54).

A number of articles discussed the benefits of citizen science for participants' development, understanding and behavior, as well as social justice and scientific outcomes (55). Practical benefits included the opportunity to conduct research '*in situ*' and to incorporate data collection and evaluation within the same tools (53). Combining citizen science approaches with big data was also seen to offer opportunities (56).

The relatively small number of articles, as well as content of a number of articles, suggested that citizen science has yet to be fully explored in social science contexts (26), or could be hidden within interdisciplinary projects where the scientific focus took most attention (47). Nevertheless, a number of benefits and constraints for citizen social science, as some articles described it, were identified.

# 3. Discussion

In summary, we found that there are emerging examples of projects taking place in both health and social science settings, which are utilizing a citizen science approach. Throughout the articles several key benefits and constraints in relation to citizen science were noted (Figure 2). These examples, and the literature resulting from them, suggests there are numerous opportunities to embed citizen science within a health or social science-based activity. These include citizen sciences potential to address societal needs, its benefits for participants and researchers, and applicability to situations that impact on our daily lives, making citizen science amenable to the context of research on death and dying.

For researchers, working on sensitive subject areas like death, dying, and end of life care, citizen sciences removal of lab-based and experimental settings provides opportunities to generate continuous data in real-life contexts, which could also include educative,

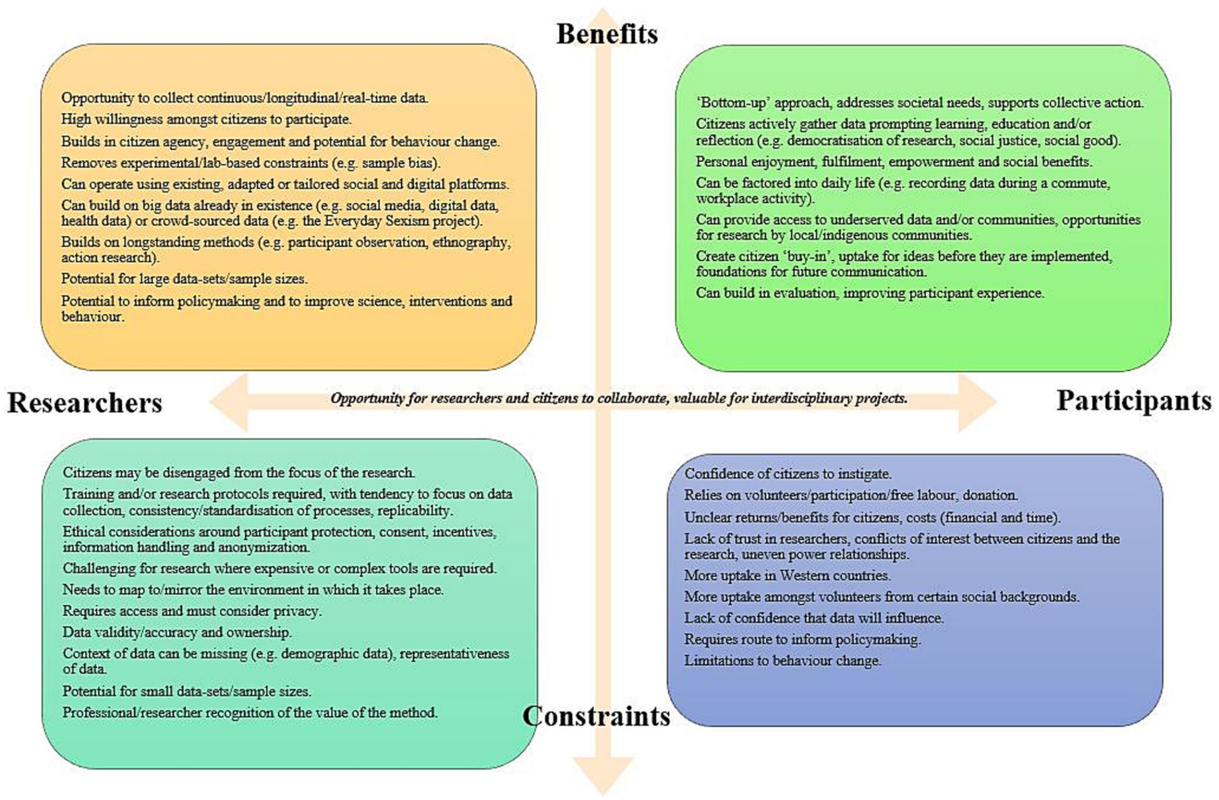


FIGURE 2
Benefits and constraints of citizen science for researchers and participants.

therapeutic or supportive aspects for those participating (4). This may also mean such an approach can reach groups of people, who are otherwise underserved, for instance by working with communities when there are spiritual, social, or cultural variations in attitudes and practices toward death and dying, or encouraging men, for example, to engage in conversations around death and dying in gendered contexts (57).

Utilizing citizen science, including via social or digital media or community-based approaches, allows participants to contribute at times and in ways that are suited to their personal contexts, providing a level of empowerment and ownership, and also allowing citizens to shape and develop the approaches used. This may mean, in the right contexts, citizen science could work effectively around some of the most sensitive aspects of death and dying, for example the loss of infants and young children, or people who have died from suicide.

However, some of the benefits of citizen science in broader settings may not apply in the context of death and dying research. For example, digital and social media approaches may provide a sense of anonymity, which would be welcome for some participants and subject areas but feel impersonal or insensitive to others. This constraint may be particularly difficult given death and dying is a subject area where people already have a reluctance to share and converse (12). Similarly, while, citizen science works well in 'everyday' contexts and therefore offers benefits for integrating research on death and dying in social, community and family-based conversations, for those currently experiencing illness, the care of others, bereavement, or loss, it can already be a challenging and stressful time to seek to accommodate any kind of extra task.

There are clear constraints in citizen science, including considering ethical implications, the limitations of data, and appropriately recognizing the role of citizens in the research, which may be even more important around sensitive topics. Citizen science may not be well suited to such topics if the potential gain for those participating is unclear. Building trust would be essential and that would take time, and it would also be vital to ensure adequate support mechanisms were in place for the lived experiences and emotions that engagement on such topics can raise. From the researcher's perspective this would require financial and time investment, to fully consider the ethical ramifications of a citizen science approach in this area and to make sure it was fully clear how any data was being used. One constraint which is arguably less applicable in the case of citizen science on death and dying is relevance, as the topic is relevant to all, but given the challenges in opening conversations in this area and indicating that relevance (12), creating uptake for such an activity, unless citizen led, would also require careful planning.

While our scoping review found that some projects and case studies included involved health conditions that could result in death and dying, it was evident there were no citizen science projects specifically focused on these topics, or end-of-life care at the time the review was undertaken. However, scoping reviews are limited in scope (33) and therefore further research would usefully ascertain the potential of a citizen science approach, as well as other public engagement techniques, in research on death and dying. To return to our original question, is there a role for citizen science in death and dying research, there is certainly potential, however any such approaches must proceed with time, care and compassion.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

## Ethics statement

The studies involving humans were approved by UWE Bristol University Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

## Author contributions

CW, AL, and CM contributed to conception and design of the research. CW conducted the initial scoping review and wrote the first draft of the manuscript. AL and CM contributed to the scoping review analysis. All authors contributed to manuscript revision, read, and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



## Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1241239/full#supplementary-material

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# Beyond the usual suspects: using cross-sectoral partnerships to target and engage new citizen scientists

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Citizen science offers enormous benefits to enhance public knowledge and understanding of science. Several opportunities to engage and share information with citizens are possible in citizen science projects. Recent evidence demonstrates however that individuals who participate in citizen science projects are demographically speaking not very diverse. For citizen science projects to successfully achieve their full potential in increasing public awareness and understanding of science, a wider social demographic needs to be engaged. We present a nationwide approach developed to achieve just that with respect to targeting and engaging residents in Denmark that did not previously have a prior connection to or interest in nature. Under the auspices of a campaign entitled *Our Nature,* our approach included the formation of a new, cross-sectoral partnership, and co-creating and implementing of a wide array of communication tactics and nature-based activities, including the development of a new citizen science project. Our cross-sectoral partnership allowed us to broaden the sectors of society that could be reached and develop cross-disciplinary activities to achieve goals for broad engagement. Extensive third-party evaluation revealed that 70% of the Danes interviewed across the country heard about *Our Nature*, and 70% of these gained more knowledge about Danish nature through the campaign. In addition to presenting our co-created projects and activities by working cross-sectorally and interdisciplinarily, we discuss the successes, challenges and limitations related to reaching our goal, based on evaluation results and our own experiences in citizen science and science communication. The citizen science project *Denmark Explores* that emerged from this campaign is used as a case study to demonstrate how our approach facilitated the broad engagement of citizens across the country−−beyond the usual nature enthusiasts.

KEYWORDS

**citizen science, science communication, co-creation, science engagement, phenology, cross-sectoral partnership**

## 1 Introduction

Citizen science offers enormous benefits to enhance public knowledge and understanding of science (Bonney et al., 2016). Throughout the life of a citizen science project numerous and diverse opportunities to engage and disseminate scientific information with citizens are possible. Scientific communication can be carried out from the initial onset of a project such as for the recruitment of participants, throughout the project to motivate and retain participants, and to disseminate project results (de Vries et al., 2019). However, for many citizen science projects, "who" the citizen scientists are, and how good the reach is in terms of improving public understanding in science is very much in debate. Recent studies from the United Kingdom and United States demonstrate that individuals who participate in citizen science projects are demographically speaking not very diverse. Citizen scientists were found to be well-educated, with up to a fifth of participants holding advanced degrees, and were middle-aged, white, and predominantly male (Dawson, 2018; Cooper et al., 2021; Pateman et al., 2021; Allf et al., 2022).

In citizen science projects that are focused on biodiversity monitoring, amateur naturalists and nature enthusiasts are the usual participants (e.g., see Richter et al., 2021). Members of nature enthusiast groups are easy to engage, and in many cases already have competencies that facilitate biodiversity and environmental data collection, meaning that they may not need specialized training to complete their tasks. The type and frequency of science communication may not have to be customized as the gap between scientist and citizen scientist in such scenarios is not so large. While this model is arguably the easiest for researchers to follow with respect to the ease and quality of data collected, the relative societal reach and gain in terms of science education is arguably limited. In order to successfully achieve the full potential of citizen science in terms of increasing public awareness and understanding of science, and to narrow the gap between researchers and the public, a wider social demographic needs to be engaged.

New strategies and approaches are being sought to reach a broader range of the public and improve the benefits of citizen science (Paleco et al., 2021; Senabre Hidalgo et al., 2021). The move toward inclusion and diversity in citizen science—i.e., the "engagement from all members of society, regardless of their social status, sociocultural origin, gender, religious affiliation, literacy level, or age" (Paleco et al., 2021)—is right at the core of today's citizen science movement though still in its infancy (Cooper et al., 2021; Allf et al., 2022; Ellwood et al., 2023). Making science engagement activities accessible for all to participate in is also increasingly being recognized (Howlett et al., 2021; Worm et al., 2021). Many of the principles of inclusion and diversity, including meaures to address accessibility, can be drawn on to achieve a greater level of citizen engagement. For example, tactics to increase the reach and achieve greater inclusiveness and diversity in citizen science can include involving citizens and/or civil society organizations in the co-creation of citizen science projects (Hickey et al., 2018; Chesser et al., 2020; Hildago et al., 2021), adopting new communication strategies and improving efforts to work collaboratively between academic, private and public agencies and/or cross-sectorally (Humm and Schrögel, 2020; Paleco et al., 2021), meeting people "where they are" (Humm and Schrögel, 2020), planning for a multitude of "entrance points" and various levels or types of participation (Kidney and McDonald, 2014; Lee et al., 2014; Humm and Schrögel, 2020), and fine-tuning or reframing research questions to make them relevant at local scales (Paleco et al., 2021).

We present and discuss an approach developed to target and engage a diversity of residents in Denmark that did not previously have a prior connection to or interest in nature. The approach included the formation of a new cross-sectoral partnership, under the auspices of a campaign entitled "*Our Nature*" (Vores Natur), with the shared goal to co-create new science communication, outreach, and engagement activities across the entire country that would provide new knowledge and experiences in Danish nature and ultimately stimulate Danes to take an active part in nature. A nation-wide citizen science project was a focal activity co-created and implemented as part of the campaign. We present methods used to co-create science engagement activities and work cross-sectorally and transdisciplinarily. We discuss the successes, challenges and limitations related to reaching our goal for broad engagement, based on the results of an extensive evaluation of the *Our Nature* campaign and our own experiences in citizen science and science communication. The citizen science project that emerged from this campaign is used as a case study to demonstrate how communication approaches can successfully be applied to engage new sectors of society.

## 2 Materials and methods

The year 2020 was themed as the "year for Danish nature" by the Danish Broadcasting Corporation (DR) and several new media programmes were developed by DR to feature Danish nature in new and educational ways, including a high-quality television documentary about Danish nature to provide the public with a "wow" experience and motivate them to seek out their own experiences in Danish nature. Taking advantage of this unique opportunity, leading nature and environmental organizations in the country from both private and public sectors, including the Outdoor Council, Danish Nature Agency, and the newly established National Network for Natural History Museums, joined forces with DR, and a nationwide campaign entitled *Our Nature* was launched (Figure 1; see Supplementary Material for additional information). Our approach for broad engagement included working transdisciplinarily through the cross-sectoral partnership, establishing beacons for public engagement, and co-creating a multitude of outreach and engagement activities.

### 2.1 Engagement activities and events for all

The *Our Nature* partnership made use of the nature theme adopted by DR to plan synergistic activities for hands-on science communication and engagement, complementing the nature stories revealed in documentaries televised by DR. A series of workshops set up between the large number of collaborating organizations resulted in the co-creation of many new ideas for engagement activities and events. The activities were planned to stimulate interest and motivate citizens to learn about and experience Danish nature and included a new nationwide citizen science project, local activities falling under five thematic beacons, as well as other events, both in-person and online, intended to appeal to broad audiences.

Five thematic beacons of public engagement (Duncan and Manners, 2012) were designed to help to communicate the overall *Our Nature* campaign. These thematic beacons served as

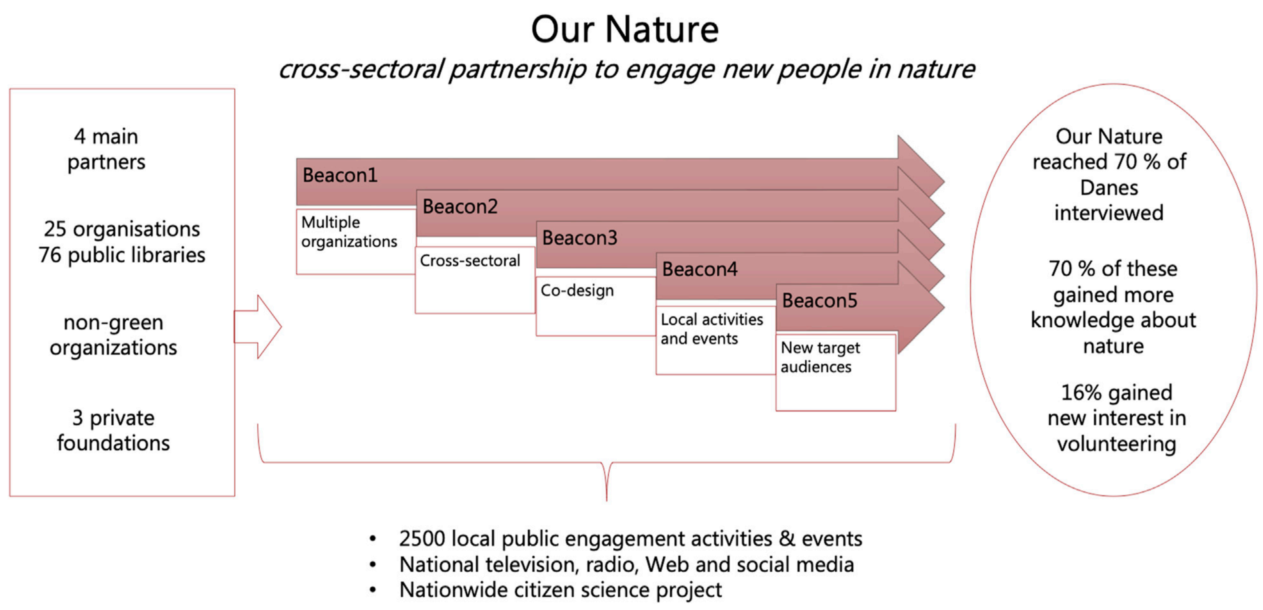


FIGURE 1
A conceptual overview of the *Our Nature* framework. The *Our Nature* partnership included four main partners: The Danish Broadcasting Corporation, the Outdoor Council, Danish Nature Agency, and the National Network for Natural History Museums. Twenty-five additional nature and/or outdoor organizations and societies, 76 public libraries in Denmark, and additional non-environmental organizations, actively collaborated with the four main partners to co-create new communication and engagement activities locally and nationally.

critical infrastructure in the *Our Nature* framework to help organize the collaborating organizations into smaller working groups and facilitate collaboration and communication activities. The five *Our Nature* beacons included: nature in summer, nature by night, nature underwater, wild food, and wild nature where you live. Multiple organizations worked together cross-sectorally to co-create and deliver local science engagement activities under each.

Funding was made available to carry-out these activities and events, with the main stipulation that activities had to be planned or offered in a way to be inclusive and attractive to new groups and reach parts of society that didn't already have an active connection to nature. These were local activities, to meet people where they are (Humm and Schrögel, 2020), across the country. The settings for activities were selected to ensure that people of all ages could participate, and many of the events were planned for those with mobility challenges in mind. In attempt to attract new user groups, many projects included cross-disciplinary activities, for example, combining bird watching with eating (wild) food, as well as activities that were planned at an introductory level or were appealing to new user groups, such a nature hike that was accessible to the inexperienced or accessibility-challenged hiker.

Examples of in person events included nature bingo, family nature walks, introductory bird watching, wildflower identification, fossil hunts, geology walks, and nights out in nature, etc. In addition, many new cross-disciplinary activities were generated such as combining hobby fishing with marine monitoring, foraging wild plants and cooking them, nature viewing in art sculpture parks, practicing yoga out in nature, and arts and crafts using material found in nature. Experienced guides and interpreters representing the participating organizations were the main modes of science communication planned for these engagement activities. In addition, online engagement activities were also offered. One example included a Q & A session intended to connect the public with researchers following the prime time viewing of DR's new nature documentary series "Wild, wonderful Denmark." A digital chat platform was created, and links were provided via DR's media channels with an invitation to all to join online and ask researchers questions about the nature content they had just seen. Three researchers from natural history museums across the country were present to respond directly to questions from the audience for one and a half hours following each show.

## 2.2 Nationwide citizen science nature monitoring project

The citizen science project "Denmark Explores" (Danmark Udforsker; Iwanycki Ahlstrand et al., 2022a) was designed to connect the themes of each of the beacons and engage people without a prior connection to nature. Citizens were asked to go out and observe seasonal events in nature (phenology) in spring, summer, fall, and winter months and help researchers gain insights to how differences in climate affects local nature. Over 50 phenology events such as the first observed flowers or the arrival of migrant birds in springtime, and the changing of leaf colour in autumn were selected by a team of scientists, nature guides, representatives from Danish media, etc. The phenology events were selected to make it easy for anyone to participate regardless of where they lived in the country and without any prior knowledge, experience, or training needed. The species were common, easy to find and identify, and while not of particular interest to taxon-specialists, they were selected to maximize the participation of citizens with diverse

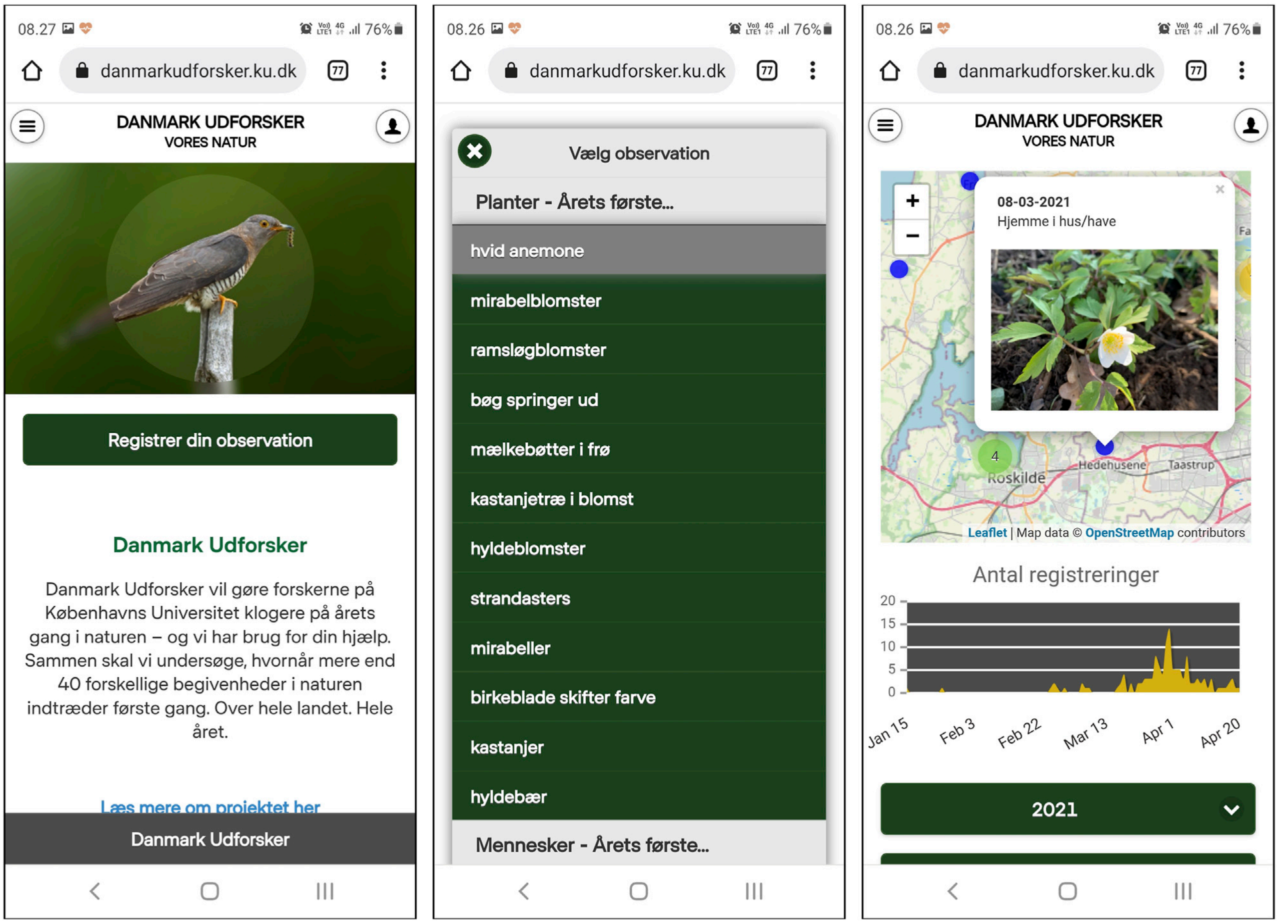


FIGURE 2
Preview of the Denmark Explores (Danmark Udforsker) web app, from left to right, home or landing page; selection of "first of the year" (årets første) plant events; and exploring observations for wood anemone (hvid anemone) in bloom.

interests. Our project was also novel because it included species/biological events on both land and in water (no location in Denmark is further than 52 km from the coast), and it importantly included several human-centric phenology events such as the first outdoor meal in spring, the first pollen allergy symptoms, and the first-time frost was seen on a car windshield. A web-based app was developed specifically for the phenology project using the domain name "www.danmarkudforsker.dk". The app allowed participants to learn basic information about the project, direct them to the phenology events that could be observed and when, and allowed participants to register their observations and interactively review the findings of others plotted on a map of Denmark (Figure 2). A more detailed description of the project, as well as detailed science information about the species and events selected for the project were prepared and made available via web pages hosted by the Natural History Museum of Denmark.

## 2.3 Communication

To engage and motivate citizens to participate in local events, we made use of multiple streams and levels of communication, including the in-person activities and events planned under each beacon, DR's media programming, and the social media platforms and websites of the lead organizations. A central webpage was created and designed to be the hub for everything related to the *Our Nature* campaign including the citizen science project. A calendar of events that was searchable by theme, location, or by the varying partners involved was made available from this website. The focus on nature programming through all of DR's media channels (television, radio, web-based) provided an incredibly unique opportunity to share information about *Our Nature*, at local, regional and national scales. In particular, the airing of their BBC-quality nature documentary during prime time over 5 weeks in early 2020 provided an unprecedented opportunity to advertise the campaign's main website and the many science engagement events and activities planned.

Another step we took was to deliberately use in-person local activities to communicate information and spread the word about other activities under the *Our Nature* framework including the national citizen science project Denmark Explores. In this way, activities that appealed to new user groups could be used as a hook to engage participants in a further suite of activities. For example, family-friendly events such as nature bingo were planned at over 20 locations across the country, and participants at these events would be introduced to the citizen science project and given a short preview of how to participate. The collaborating organizations used their own membership lists and communication channels to further share news of the activities. At the conclusion of the *Our Nature* campaign, a small conference was organized in the evening hours to allow for the presentation of results to all participating organizations. The further sharing of the final *Our Nature* results was also left up to the individual partner organizations and collaborators using their own communication channels.

Media releases and social media feeds of some of the participating organizations were used to attract participants to the citizen science project continually throughout the observation collection period (March 2020–June 2021). Individual phenology events were promoted in the days before they could be observed. Three to four phenology events that could be observed around the same time were advertised together in a single social media post; short sentences were used to communicate information about the species being observed along with an invitation to participate. With respect to dissemination, the citizen science project's results could be viewed and explored using interactive maps of citizen observations on the web-based app developed for this project (Figure 2).

## 2.4 Measuring the impact—extensive evaluation of the nationwide campaign

Extensive third-party evaluation of the *Our Nature* project and the partnership was carried out in 2020 and 2021 by Als Research (Als Research, 2021). The evaluation was set-up to evaluate the project deliverables and the targets set for the communication and engagement activities carried out in the project. Qualitative interviews were conducted by an external third-party company (Kantar Gallup, 2021), between 19 October and 25 October 2020. A media analysis to evaluate the success of the programming developed by the Danish Broadcasting Corporation was carried by Epicent (Als Research, 2021) over the period of April–October 2020. These analyses were supplemented by viewership statistics data from DR's media research group (Supplementary Figures S2, S3).

Due to privacy regulations in the EU, i.e., General Data protection Regulation (GDPR), only minimal data was collected about the participants who were engaged in our citizen science project. Name, address, or other contact details were not collected, and thus an in-depth evaluation with respect to our inclusivity goals for this project was limited. However, we report on available data (on participant gender and postal code), along with categorical information submitted with each observation about where a participant's observation was made, to infer more about the participants and our goals to improve the reach.

# 3 Results

The *Our Nature* campaign, along with the citizen science project, *Denmark Explores*, was launched in March 2020, during the week following Denmark's first lockdown due to the COVID-19 pandemic. Over 2500 public engagement activities across the country were co-created via the cross-sectoral partnership and collaborations. They were local events offered across the country and scheduled to run throughout the year 2020. The COVID-19 restrictions unfortunately led to many cancellations, delays, and changes in *Our Nature*, including cancellations of almost all the in-person activities planned under the five beacons. This means our strategy to communicate our citizen science project and other engagement activities falling under each beacon via face-to-face events was severely compromised, and communication efforts were re-focused to using social media platforms, websites, DR's programming, and only a handful of in-person events that ran in 2020. However, because our citizen science project was designed as an activity that participants could do on their own, the citizen science project it itself was unaffected. The citizen science project was extended into the early spring months of 2021 because of the COVID-19 impact.

Extensive evaluation of *Our Nature*, including following up with citizens across the country, was achieved: 1092 people in Denmark over the age of 18 years responded to the web-based survey: 27% of respondents were aged 18–35 years, 41% age 36–59, and 32% 60 years of age and older. Furthermore, respondents were reached in each of the five regions of Denmark (32% in the Capital region, 14% from Zealand, 21% from South Denmark, 23% from Middle Jutland, and 10% from North Jutland (Kantar Gallup, 2021). The evaluation revealed that our communication approach was a success: approximately 60% of all Danes surveyed had heard about *Our Nature*. The nature theme offered through all of DR's media channels reached 70% of the Danes interviewed (Kantar Gallup, 2021). The series "Wild wonderful Denmark" and "Give us nature back" had very high viewing figures (data not shown), and these new nature television programmes were seen by a wide range of Danes across age, gender, and level of education (Supplementary Figure S2). Importantly, 70% of the Danes who did encounter *Our Nature* reported to have gained more knowledge about Danish nature, 64% developed a greater desire to be in nature, 58% plan to seek out nature in the future, and (16%) would engage in voluntary nature projects, to a significantly higher degree compared to those that were not reached (Supplementary Table S1).

Our citizen science project did not benefit from the same extensive evaluation largely due to GDPR. However, we can report that over a thousand participants signed up and submitted a total of 1079 phenology observations from across the entire country in 2020 and 878 observations in the spring months of 2021 (Figure 3). Regarding gender balance, 64% of the participants were female, 35% were male, and 2% identified as "other" across both years. When submitting observations, categorical data regarding the location of the observation was registered by participants, and 50% of observations were made "close to participants' homes," 30% of observations were made "on neighborhood walks," while only 4% were made while "out in nature." The remaining observations were reported as recorded either "on the go" or as "other" circumstances.

# 4 Discussion

## 4.1 Partnership for nature

The multi-tiered and cross-sectoral communication approach we developed for *Our Nature* contributed to strengthening Danes' knowledge of, as well as desire to seek out and engage with, Danish

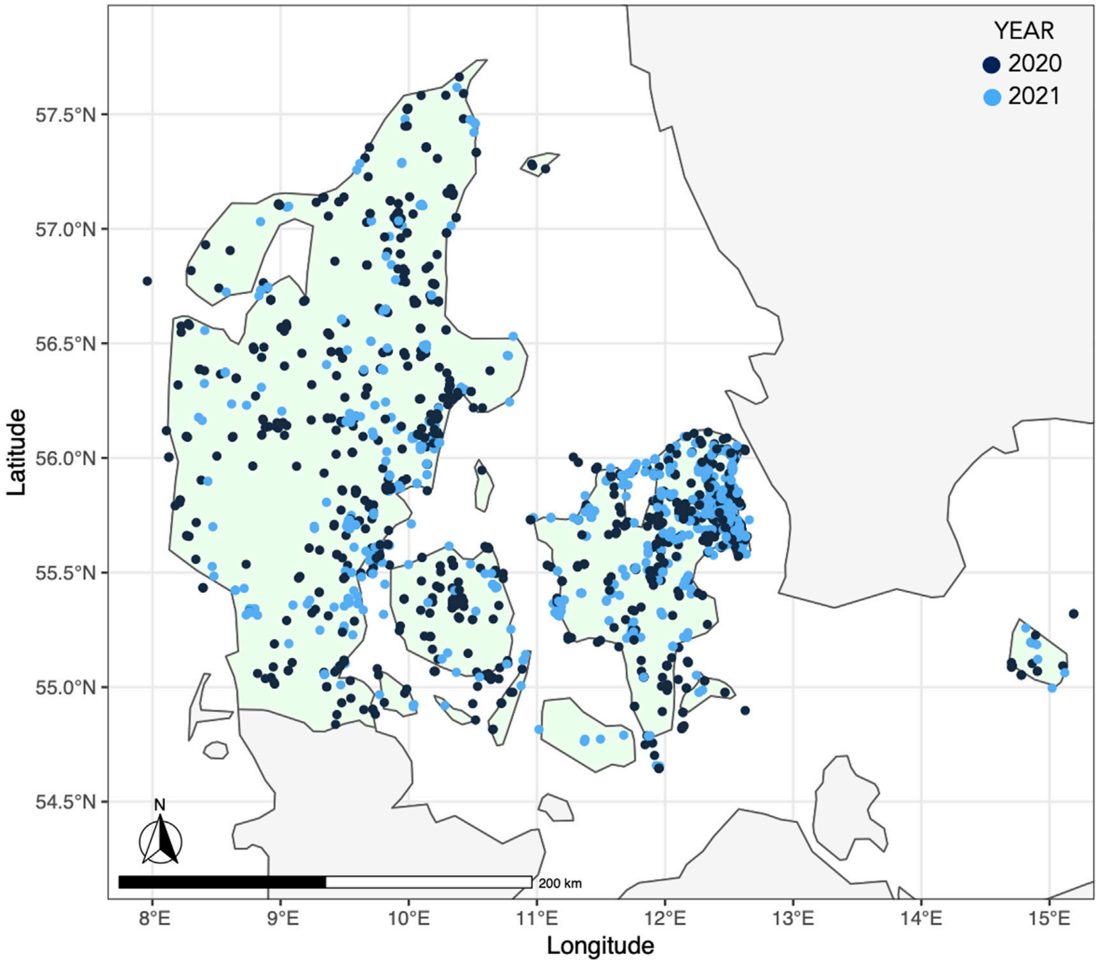


FIGURE 3
Map of Denmark including the observations made by citizen scientists for the project Denmark Explores in 2020, and 2021.

nature. The cross-sectoral partnership allowed us to co-create and implement a wide array of engagement and communication tactics to ultimately broaden the sectors of society that could be engaged. The broad media coverage of the nature theme on DR and the locally anchored activities centered around the beacons complemented each other well and would have arguably resulted in greater levels of engagement if the campaign was able to run without being subject to setbacks during the pandemic. The stipulations set by funding agencies to co-create activities that would appeal to Danes without a prior connection with nature provided excellent incentives for the participating organizations to join forces, work interdisciplinarily, think outside of the box, maximize differing strengths, and discover new synergies.

Working cross-sectorally and interdisciplinarily is critical for tackling many of the real world's "wicked" problems (McCune et al., 2021), and in our experience, regardless of the research problem being tackled, working interdisciplinarily and transdisciplinarily often requires finding a common language for what is typically very discipline-specific ways of communicating. Finding this common language between partners in the early stages of the co-creative process naturally lent itself to developing a simple language that is suitable to reach non-experts in the public, thereby reducing possible exclusion in our science communication efforts throughout the project. Our citizen science project benefited from the use of a simplified and not overly complicated language, despite the focus being on complex processes in nature such as the response of phenology to a changing climate. While in our professional experiences as biologists and citizen science practitioners we clearly understand the value of adapting our scientific language in a way that can be understood by all, having a transdisciplinary team helped in finding new ways to communicate scientific terms such as phenology, and indeed even highlighting the value of avoiding or limiting the terms "citizen science" and "climate change. As is the case in many languages, there is no suitable term for citizen science in Danish, and the name citizen science is under debate even in English speaking parts of the world for the main reason that the name may exclude people (Cooper et al., 2021; Ellwood et al., 2023).

## 4.2 Beacons of public engagement

The concept of using beacons for public engagement has gained recent attention to work with audiences not previously talked to or engaged with, including socially excluded groups. In the United Kingdom, beacons have been used to promote civic engagement in higher education and decrease the gap between university researchers and the public (Duncan and Manners, 2012), as well as to target underserviced areas of society with respect to public health issues (Rashman et al., 2005). We are not aware of any other models that used the beacon approach to facilitate the creative process of discovering synergies between partner organizations and co-creating science engagement activities together. In our approach, the thematic beacons were of greatest value to the internal framework of *Our Nature* as they allowed small groups of collaborating organizations to work together across disciplines under a common theme, magnify the potential reach of the communication and engagement activities planned, and democratically select projects to fund. While it was important to have multiple organizations working together under each beacon, we found that it was highly effective to designate a lead organization to make the beacons successful. In one situation, a beacon lacked a strong leading organization, and our experience was that the momentum of this beacon lagged behind the others until a new organization joined to take the lead. Should our campaign not have been impacted by COVID-19 restrictions, the beacons could have had a greater visibility to help attract and engage participants.

## 4.3 Activities to appeal to the masses and stimulate engagement

Our approach recognized the need for and importance of infrastructure for face-to-face collaboration and meeting (Hildago et al., 2021), and many new and exciting ideas for cross-disciplinary activities were generated. Unfortunately, the bulk of these planned activities never came to fruition due to COVID-19 restrictions. Offering multiple entry points and more than one way to participate in a project with varying levels of commitment as options for participants are considered key to ensuring a diversity of people can be engaged (Paleco et al., 2021). The activities we planned, in particular the citizen science project, did indeed provide multiple entry points and varying possibilities to participate that could appeal to a newcomer. A citizen scientist had the freedom to determine the extent to which they were involved. They could decide to report only on a single phenology event from a single location, or multiple observations could be made either for a single species event but observed in different locations, or multiple observations could be made for several or all the phenology events included in the study. They could also browse through the web material and explore data and learn something in the process, without actually submitting data.

Admittedly, it was not always easy to break the norms with respect to engagement activities, and challenges were experienced with convincing participating organizations to modify their existing tactics to meet the campaign's goal to reach a new sector of society and engage them with nature. Our experiences revealed in some instances that a major push was needed to get groups to think outside the box, even when financial support was offered as an incentive. An overall shift in thinking and breaking down barriers between participating groups was essential, and an unbiased facilitator could have been useful to guide participants in this direction.

An example of a new science communication activity that worked very well to bridge the gap between researcher and member of the public was the online engagement forum planned for the hour and a half following the new nature series televised on DR. Three researchers/experts in the fields of science that related to the nature stories portrayed in the documentary were available to chat and answer questions from the public. Each scientist was able to interact with at least 25 members of the public, and the public could follow the Q & A chat online. This model could be very effective in future science communication efforts. While we can report on the success of this initiative, we unfortunately do not have data to assess if a new audience was reached.

## 4.4 National citizen science project to attract first-time nature observers

Phenology has emerged as a key metric to study biological response to climate change and while numerous citizen science phenology projects exist (Mayer, 2010; Beaubien and Hamann, 2011), most are centered around monitoring several phenological phases on, for example, a plant or plant population. These types of citizen science projects require training and aren't always well suited to all (MacKenzie et al., 2017). Because we had the goal of involving citizens who did not previously have a connection to nature, we believe that we did encourage a greater level of inclusivity in Denmark Explores by adapting our research questions and communication strategy. We focused on species that are found everywhere (Johnson, 2016), and included phenology events that were human-centric as a hook to attract people with other interests, rather than preaching to the converted (Allf et al., 2022). Furthermore, we benefited from the cross-sectoral partnership and the efforts made to reach new participants using new channels. While from a researcher's point of view it perhaps isn't as attractive to study very common organisms, we would agree that at least in the study of phenology, so little is known about impacts of recent climate warming on even the most common species, and our project could still unravel novel scientific findings (Iwanycki Ahlstrand et al., 2022b). Finding the right balance between research questions that could both help promote inclusivity and deliver new scientific research is therefore key.

While participant interviews or other evaluation metrics were not possible, we did find that citizen science participants were predominantly female, which differs from participant survey results from other studies (i.e., Allf et al., 2022). Half of observations were made close to participants' homes, and our human-centric events were among the most popular and therefore we believe these results to be telling signs of the successful engagement of participants that are not the typical nature enthusiasts. We acknowledge though that the pandemic may have inflated the numbers of people making observations from home because of following isolation restrictions.

Several factors hindered our goals for broad engagement in our citizen science project and are worthy of mention. Our project relied solely on a digital app to report findings. While this makes it easy for everyday citizens to participate, it meant that we excluded anyone who doesn't carry a smartphone or use a computer–or is challenged with respect to text literacy. Also, all our programming was run entirely in Danish, and although this is the official language in Denmark, some residents are not fluent in Danish, and these are likely the most excluded sectors in society and most likely not reached through this project. To truly reach these sectors, one would have to work with translators and members of the minority groups in the country, possibly by appointing community group ambassadors to help with this.

Finally, limitations with respect to privacy and GDPR meant that we could not communicate directly with individuals participating in the project. This means we did not have the opportunity to share project results along the way, provide continued motivation and/or incentives, or disseminate results of the final project with individual participants. We recognize that citizens want to hear about results, have access to the data they collected, and be acknowledged in research articles (de Vries et al., 2019). Our efforts to disseminate results was limited to using the project's webpages and through our social media platforms. It is possible, though difficult to measure, that even though we reached a limited demographic using these dissemination tactics, that these participants will bridge the gap between researchers and the other participants (Damiani et al., 2021). One solution to this dilemma in future citizen science projects would be to place an even greater involvement of citizens and citizen society organizations in the early stages of the project, allowing researchers to have a greater number of direct connections to the participants and obtain special permissions to allow for follow-up.

Our results confirmed a broad interest in participating in citizen science projects and engaging in local nature and environment, and, more specifically, to contribute to a phenology project. After the official conclusion of the *Our Nature* campaign, the Network of Natural History Museums have continued to collaborate and have further developed Denmark Explores, moving the project to the national biodiversity reporting platform "Arter" (www.arter.dk), where in 2023 more than 2000 observations were received focusing on spring time phenological events (Iwanycki Ahlstrand and Tøttrup, unpublished data).

## 4.5 Concluding remarks

There are many excellent reasons why inclusion and diversity–and achieving broad participation–have become trends in citizen science projects and generally in science communication (Humm and Schrögel, 2020). In our experience, it can be difficult to design a one-size-fits-all citizen science project on the first go, simultaneously incorporating measures to improve inclusion and reaching the broadest audience possible. Citizen science projects come in a diversity of forms, which vary immensely with respect the level of citizen involvement, level of prior knowledge, specialized skills or training needed, and level of commitment (resources). However, sharing community knowledge and collaboration will enable more citizen science practionners to improve the inclusiveness of citizen science projects. This is naturally underpinned by the fact that all projects should provide a benefit to all individuals involved, both the professional scientist and the citizen scientists (ECSA, 2015). In the case of Denmark explores, our goals to engage participants who did not yet have a connection to nature, are closer to the goals of science communication: to reach the broadest audience possible, and our goals for high-quality data collection came second to this. We have however demonstrated that with the right research questions and communication approach, inexperienced nature observers can contribute meaningful data, and that data from such participants balances any biases associated with participants from homogenous backgrounds (i.e., nature enthusiast) (Sorensen et al., 2019).

Not all citizen science projects are run at national levels, nor do they have access to the same level of resources as was available to support the extensive partnership and activities created through the *Our Nature* campaign. However, several principles applied in our approach could be applied to projects of varying scales, with or without the incredible momentum provided by an agency such as the largest media group in Denmark. What we believe to be key elements of success here are 1) the creation of a partnership that spans sectors and varying types of organizations, 2) having incentive to work collaboratively and interdisciplinarily to co-create ideas and tactics under thematic beacons, and 3) planning hooks to draw in target audiences such as cross-disciplinary events or activities that can serve a steppingstones to others.

## Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

## Author contributions

NIA: Conceptualization, Formal Analysis, Investigation, Methodology, Visualization, Writing–original draft, Writing–review and editing. APT: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Visualization, Writing–review and editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1254047/full#supplementary-material

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# Interrogating illusions of progress: citizen science, science communication, and a call for inclusive reform

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## 1 Introduction: The role of conferences in research and practice

With their foundations in Ancient Greek symposia, progression to eighteenth-century French salons and coffeehouses, up to modern incarnations of large-scale international meetings, conferences have a rich history of bringing scholars together to communicate new views, opinions, and research findings (Nicolson, 2017; Roche, 2022). Conferences are not only significant vehicles for generating scientific and societal impact (Hauss, 2021), but are critical in shaping professional identities (Kuzhabekova and Temerbayeva, 2018). Consequently, researchers are often expected to attend conferences as a central part of their career progression (Egri, 1992; Kriwy et al., 2013; Sousa and Clark, 2017), in order to network, collaborate, and ultimately boost their productivity and creativity while sustaining and supporting subfields of research (Coser, 1997; Gross and Fleming, 2011; Campos et al., 2018).

There is an argument that conference attendance is by its nature "egoistic," with researchers being able to visit "wonderful places, partly or wholly financed by our employers" while furthering career prospects by connecting with "people who might have powers to open doors" (Edelheim et al., 2018, p. 98). The conferences themselves can often be "a darn good party, with dancing, music, good food and drinks, and [. . .] the company of like-minded people" (Edelheim et al., 2018, p. 98). The varied accounts of why researchers attend conferences span the range "from secret affair to dull duty," and include niche reasons such as "seeing friends, hotel swimming pools, tourism, heavy drinking or the taking of drugs" (Parker and Weik, 2014, p. 169–170). Equally, conference attendance can be rooted in something far nobler, the taking of a stand, on some of the grandest stages available to research communities to call for "renewed commitment to responsive, equitable, and inclusive practice" (Brown et al., 2020, p. 1). Overall, however, not enough research has been conducted on the impact of conferences or the motivations and needs of the conference delegates themselves (Rowe, 2018; Hauss, 2021). Conferences should be places where the "cutting edge of new conceptual thoughts, research and views are presented, discussed and debated" (Hobson, 1993, p. 115). Despite their importance to research, conferences are plagued by a lack of inclusion, with some people made to feel uncomfortable or intimidated, or actively discriminated against (Settles & O'Connor, 2014; Biggs et al., 2018; Timperley et al., 2020).

Judd and McKinnon (2021) present a detailed map of inclusion in science communication and highlight how a key challenge for the field is the absence of universally accepted definitions for inclusion, diversity, equality, and equity. More broadly, even the role of inclusion in education is contested, with tensions between different interpretations around the world, and no unifying definition (Banks, 2022). Despite societal impact being difficult to define (Bornmann, 2013), one aspect of inclusion that is uncontested is its immense benefit for research, education, and society (Hong and Page, 2004; Puritty et al., 2017; Grier, 2020). Inclusion is best served by defining it within the context in which it is being discussed. For the fields of science communication, citizen science, and public engagement, inclusion might be considered conceptually "as a process of cultural boundary crossing and exchange" (Bevan et al., 2020, p. 8). In practical terms, inclusion can be defined as "the early and active engagement of a wide range of actors and stakeholders to take their needs and concerns into account from start to finish" (Achiam et al., 2022, p. 2). Conferences are already places of immense privilege but for truly "socially inclusive science communication" it should happen "where people spend most of their time—within their communities" (Streicher et al., 2014, p.1). Geographical, environmental, and financial barriers have long hindered researchers from attending conferences (Grémillet, 2008; Timperley et al., 2020). Parker and Weik (2014) alluded to the myriad personal barriers that exist—for many to attend conferences "it is necessary to leave someone else with the burden of care" (p. 170). As conferences are integral spaces for research communities to come together, better inclusive practices for researchers and conferences will result in a fundamental outcome of inclusion that leads to countless subsequent benefits—the strengthening of community (Quick and Feldman, 2011).

As with all established fields of research, the domains of citizen science, science communication, and public engagement have conferences that are central to their communities. Citizen science is most commonly considered an approach to scientific research that incorporates people or groups who do not identify as professional scientists (Bonney et al., 2009; Silvertown, 2009), as well as being a field of research in its own right (Kullenberg and Kasperowski, 2016). Science communication, a field of both practice and research, involves the exchange of knowledge, often between scientific experts and public audiences (Burns et al., 2003; Trench, 2008; Bultitude, 2011), while public engagement is understood to be a practice that also involves various publics in science (Rowe and Frewer, 2005; Stilgoe et al., 2014). There are a number of similarities and synergies among the fields, and together, they have the potential to strengthen trust between science and society (Golumbic et al., 2020; Roche et al., 2023).

In 2023, some of the largest and most important citizen science, science communication, and public engagement conferences took place within a 3-month period from April to June. The conferences are organised and attended by communities of researchers and practitioners who have identified inclusion as either being integral to their values or an area that needs more consideration. This paper explores how issues of inclusivity were discussed at those conferences. The authors of the paper are all members of the Science & Society Research Group at Trinity College in Dublin. As well as comprising researchers who regularly attend the main citizen science, science communication, and public engagement conferences, the group is based in a School of Education that has its values rooted in inclusion, equity, and social justice, making the group ideally placed to critique the conferences and reflect on how issues of inclusion are currently being tackled.

## 2 Inclusion at conferences in 2023

Four international conferences in the fields of citizen science, science communication, and public engagement were held between April and June 2023: the PCST, C*Sci, EUSEA, and Ecsite conferences. The largest science communication conference is the biennial conference of the PCST (the Public Communication of Science and Technology) Network, (Featherstone, 2014; Treffry-Goatley, 2014; Wang and Liu, 2016; Joubert et al., 2019), with sixteen conferences on six continents since 1989 (Fayard et al., 2004; Gascoigne et al., 2010). PSCT 2023 took place in Rotterdam from April 12th to 14th. The theme of the conference was Creating Common Ground, and included five sub-themes: values, openness, inclusiveness, collaboration, and expertise. Examples of conference sessions where inclusion was discussed include the following: 'From goodwill to inclusive and equitable practices–an introduction to inclusive science engagement', 'Citizen science and scientific communication: toward a more inclusive pattern', and 'Reflections on justice, equity, diversity, inclusivity and decolonising science communication'.

The following month, C*Sci 2023 took place in Tempe, Arizona, from May 22nd to 26th. C*Sci is the main conference of the (US) Citizen Science Association (Storksdieck et al., 2016; Roche and Davis, 2017). Examples of conference sessions where inclusion was discussed include the following: 'Inclusion, Equity, and Accessibility in Large-scale Projects: Successes, failures, and not-yets' and 'Designing for Action and Impact, Practices for Justice, Equity, Diversity, and Inclusion, Building Relationships and Community Trust'.

As well as the flagship biennial conferences in the fields of citizen science and science communication taking place weeks apart in 2023, there were also two annual science engagement conferences that occurred around the same time. The first was the annual conference of the European Science Engagement Association, EUSEA. Although a smaller conference compared to the others on this list, EUSEA has an equally strong focus on inclusion, with the first of its four values in its mission statement being 'Diverse and Inclusive'. #EUSEA23 took place in Bolzano, Italy, from May 3rd to 4th.

This was followed by Ecsite 2023, the largest annual science engagement conference in Europe (Roche et al., 2018; Mignan and

Joubert, 2022), which took place in Valletta, Malta, from June 15th to 17th. Ecsite 2023 had a special focus on the theme of Equity & Inclusion with all session submissions being rated against their alignment with Ecsite's core values of diversity and inclusiveness at the selection stage. Examples of conference sessions where inclusion was discussed include the following: 'Equity and Inclusion in and through evaluation' and 'Welcome, everyone: using inclusive language in museum spaces'.

From the conference programmes, it can be seen that inclusion was tackled to some extent at all four conferences, which led to discussions around the role of inclusion in practice as well as the practice of inclusion itself at conferences. During the session on justice, equity, diversity, inclusivity, and decolonising science communication at PCST 2023, numerous audience members raised critical issues including the responsibility of professionals within the mainstream to push for meaningful action and change regarding more inclusive science communication research and platforming, rather than placing the burden of change-making solely on those experiencing these injustices. Without adequately sharing this responsibility, and seeking to forge this change as a community, researchers and practitioners, whether inadvertently or not, continue to perpetuate these inequalities. At Ecsite 2023, a key session was 'Moving the dial: integrating community priorities into citizen science' which tackled the challenge of distinguishing between community science and citizen science. This discussion around the choice of terms between citizen science and community science also emerged at the final plenary of #EUSEA23 in a discussion about the role of research funders in connecting research with society and the significance of the terms: 'science', 'citizen science', and 'community science'.

The distinction between terms was also a recurring topic at C*Sci 2023. The terminology in citizen science has always been a complex issue (Eitzel et al., 2017) and the debate around why the 'citizen' aspect of the term might be insensitive to systematically marginalised populations (Ellwood et al., 2023; Lin Hunter et al., 2023) led to the Citizen Science Association (CSA) changing the conference name to C*Sci (to include both citizen science and community science) and rebranding the CSA itself to become the *Association for Advancing Participatory Sciences*. For participants to feel included at conferences and to feel that their contributions matter to their fields of research, inclusive terminology is critical (Baeckens et al., 2020; Canfield and Menezes, 2020). Changing the term 'citizen science' due to calls for greater inclusivity is a well-supported argument. Equally valid, however, is the argument that decades of work have been invested in making the term 'citizen science' credible and recognisable in terms of funding, resources and policy, and abandoning it altogether might inadvertently harm the engagement prospects of those the rebranding is trying to reach (Haklay, 2023). Regardless of people's position on such arguments, what is clear for the field is that work remains to be done: "The challenges of inclusion in citizen science reveal that words—no matter what the terminology—and intentions—no matter how good—are not enough" (Cooper et al., 2021, p. 1388).

## 3 Discussion: Inclusive practice for conferences

The COVID-19 global pandemic transformed conferences in terms of accessibility, cost, and carbon emissions (Jäckle, 2021; Medina and Shrum, 2022). Although issues of inclusion remain around those who have internet access and access to technology—often referred to as the *digital divide* (Venkat, 2001)—the overall increased accessibility and reduced environmental impact mean that virtual conferences and hybrid conferences are likely to become even more commonplace (Klöwer et al., 2020; Sarabipour et al., 2021). Researchers have a responsibility to provide climate leadership and change conference culture (Parncutt and Seither-Preisler, 2019), while conference organisers have a responsibility for future events to be "rooted in sustainability, equitability and inclusion" (Niner et al., 2020, p. 253).

In science communication, citizen science, and public engagement, many initiatives go unnoticed and unacknowledged because the people, practices, venues, content, or context are treated as unworthy of attention (Orthia, 2020; Finlay et al., 2021; Chiaravalloti et al., 2022). These exclusions are further perpetuated by the academic structures and hierarchies that conferences, and indeed most researchers themselves, must operate within. This can discourage and even stymie the progress of early career researchers, especially those from underrecognised communities. Researchers on precarious contracts are often not eligible for the same financial support to attend conferences as senior academics. Tackling inclusion in conference settings is not a new pursuit. The main topic of the PCST conference in 2014 was "science communication for social inclusion and political engagement", while the Ecsite conference in 2014 had "at least seven sessions devoted to social inclusion" (Massarani and Merzagora, 2014, p. 1). Conferences are also part of the larger academic ecosystem which, without direct intervention of its participants, will continue to uphold and reify exclusion of individuals, groups, and initiatives whose marginalisation has been baked into academic practice (Henrich et al., 2010; Rubinger et al., 2020; Judd and McKinnon, 2021).

Davies' (2023) account of PCST 2023 thoroughly reflects the experience of this paper's authors and is endorsed by the group and recommended as an exemplary conference review paper. It celebrates the positive aspects of the conference, such as the atmosphere and the richness of the sessions, but does not shy away from calling out the uncomfortable topics that need to be addressed, such as the history of oppression in science (Davies, 2023). While experiencing the largely welcoming and friendly atmosphere, some of the co-authors of this paper noticed an underlying hierarchy amongst attendees, as is present at many large-scale conferences, with the "stars and nobodies, insiders and outsiders" (Henderson, 2015, p. 914) being treated differently. Most egregious however were the "attempts to foreground colleagues from the Global South," which, especially in a dedicated plenary session, were "exoticising, paternalistic, and disrespectful" (Davies, 2023, p. 3). To address such issues, we need to act with "humility and courage, to reform our approaches" (Brown et al., 2020, p. 4). The most important voices to listen to are those tackling the biggest challenges of inclusion. Organisations like *Diversci* (which is a collective of science engagement professionals advocating for more inclusion, equity, diversity and social justice within the science engagement community) and *SACNAS* (an organisation dedicated to fostering the

STEM success of Chicanos/Hispanics and Native Americans) continue to advocate for the type of inclusion that conferences need to achieve. Conferences would benefit from "the expertise of those in the majority world or in marginalised groups" when it comes to setting an agenda for inclusive reform (Davies, 2023, p. 3). Canfield and Menezes (2020, p. 13) identify three key traits of inclusive science communication which must "exist concurrently", and can be drawn upon to recommend concrete actions for future conferences in science communication, citizen science, and public engagement.

1. Intentionality: At the outset, conference organisers should give intentional consideration to the goals of the audience and detail how the conference addresses representation, terminology, and support, especially for underserved or underrecognised communities.
2. Reciprocity: At the planning and implementation stages, representatives of the conference audiences should be involved, supported, and recognised for their varied forms of expertise to provide more diverse leadership in a cocreation process that prioritises equal partnership.
3. Reflexivity: After the conference, a systematic evaluation should be undertaken to assess inclusivity at all stages of the conference, coupled with changes and recommendations to address any identified inequities.

## 4 Conclusion

As with all science communication, making conferences more inclusive may require "critically assessing current practices, perspectives and motivations in combination with a concerted call to action that places equity at the heart of science communication, rather than on the periphery" (Dawson, 2014, p. 3). To achieve true inclusivity in citizen science and science communication, radical systematic change is needed "whereby inclusion, equity, and intersectionality ground all research and practice" (Canfield et al., 2020, p. 2). Such change is a continuous process that requires regular reflexivity (Dawson et al., 2022) and conference organisers must reflect on both successes and failures when it comes to inclusion, and actively work to make improvements. Conference planners need to consider mobility, cost, environmental impacts, and strive for more sustainable events. Diversity, equity, access, and inclusion need to be embedded in the planning, financing, marketing, scheduling, evaluation, and reporting stages of conference development. As conference attendees, we must not settle for illusions of progress, and instead actively confront the contemporary realities of racism, sexism, ableism, and other forms of discrimination—biases which are corrosive to human dignity—embedded within our fields of research and practice and within ourselves.

## Author contributions

JR: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Writing–original draft, Writing–review and editing. GB: Writing–original draft, Writing–review and editing. LB: Writing–original draft, Writing–review and editing. AB: Writing–original draft, Writing–review and editing. SC: Writing–original draft, Writing–review and editing. OD: Writing–original draft, Writing–review and editing. AF: Writing–original draft, Writing–review and editing. SH: Writing–original draft, Writing–review and editing. MH: Writing–original draft, Writing–review and editing. AK: Writing–original draft, Writing–review and editing. AL: Writing–original draft, Writing–review and editing. AC: Writing–original draft, Writing–review and editing. AM: Writing–original draft, Writing–review and editing. EN: Writing–original draft, Writing–review and editing. FS: Writing–original draft, Writing–review and editing. AT: Writing–original draft, Writing–review and editing. SU: Writing–original draft, Writing–review and editing. AW: Writing–original draft, Writing–review and editing. CW: Writing–original draft, Writing–review and editing. KZ: Writing–original draft, Writing–review and editing.

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# A framework for making citizen science inclusive with storytelling methods

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Citizen science is challenged by a participation inequality that is not compatible with a democratic approach to science. To include the voices of underrepresented groups, this article presents "STORCIT", a framework for making citizen science inclusive with storytelling methods. This framework was trialed in the project "Climate Stories" with two small-scale pilot studies in Hasselt and Brussels (Belgium). This project involved around 50 young people with a diverse background, since they are often overlooked as agents of change in the climate debate. During the project, they recorded their experiences related to the changing climate through citizen science and storytelling methods. The STORCIT-framework was designed through five consecutive phases: i) setting the scene, ii) generating knowledge and learning, iii) sharing personal narratives iv) developing stories, and v) exhibiting to the public. The results reflect on the implementation of this approach, together with the experienced challenges, limitations, and gains. Overall, the approach is highly participatory, multi-faceted and supports the democratization of knowledge generation. The gathered knowledge helps participants to reflect on their story, raise their voice and catalyze actions for social change. In the context of citizen science research, practitioners are encouraged to explore and further adapt this framework to other (justice) domains and involve other vulnerable target groups. In particular, it can be deployed by those who aim to include diverse audiences and stimulate inclusive dialogue between science, society and policy with actions for social change.

KEYWORDS

**citizen science, participatory action research, storytelling, photovoice, dialogue, inclusion, youth, climate change**

## 1 Introduction

Citizen science (CS) is referring to a diverse set of activities in which the public can participate to generate new knowledge or understanding. It is an approach for realizing public participation in science (Bonney et al., 2009), by which a two-way communication is favored to transmit science information (Rüfenacht et al., 2021). In different degrees of participation, researchers and citizens interact and collaborate to define the project design, the analysis and dissemination of findings (Shirk et al., 2012; Haklay, 2013). By making the scientific process participatory, CS holds the promise to democratize science (Strasser et al., 2018; Herzog and Lepenies, 2022). One particular meaning of democratization refers to the inclusion of citizens, through a representative sample of the general population, in the decision-making processes (Strasser and Haklay, 2018). In this sense, something becomes more democratic when people, especially those who have a stake can take part (Strasser et al., 2018). However, from the available demographic analyses of CS projects, it seems there exists a clear participation inequality. People with less formal education, people of color, younger people and women seem to be underrepresented in CS projects (Raddick et al., 2013; Merenlender et al., 2016; National Academies of Sciences, 2018). This lack of broad participation is not consistent with a democratic approach to science and affects the quality of CS projects (Pandya, 2012). Furthermore, the under-participation of certain groups might result in their concerns, wishes, and needs not being considered in the research, or that they might not benefit from certain outcomes. This can reinforce existing inequities in society and, especially, when the research overlooks groups who are often disproportionately impacted by environmental hazards (Grineski et al., 2022).

To leave no one behind and to fully leverage the democratic potential of CS, more inclusive approaches are necessary. In this regard, various efforts in the field are being established to develop new frameworks for wider and deeper public engagement with science. For instance, the "DITOs escalator framework" of Skarlatidou and Haklay (2021) that helps people to decide which level of engagement is suitable for them, or the framework of Pandya (2012) with specific design recommendations to better align with community priorities. There are also various case studies and initiatives which are looking into establishing collaborations with other approaches, such as participatory action research (PAR), community-based research and transdisciplinary research (e.g., Paleco et al., 2021; Senabre Hidalgo et al., 2021).

Against this backdrop, this article proposes a new framework for making citizen science more inclusive with storytelling methods, called "Storytelling in Citizen Science" or short "STORCIT". This framework builds upon the synergetic potential of CS and PAR, with photovoice and digital storytelling as main methods. PAR is an umbrella term to cover diverse participatory approaches and action-oriented research studies which seek for socially and environmentally just outcomes (Kindon et al., 2007). In comparison to CS, a strong collaborative nature between researchers and participants is also present in PAR, whereby participants act as "co-investigators" (Freire and Ramos, 1970). However, the action-oriented approach is not always that prevailing in CS, especially when participants are involved as mere data gatherers in contributory projects (Chevalier and Buckles, 2019; Senabre Hidalgo et al., 2021). By drawing on these two streams of thought, photovoice and digital storytelling are being put forward as main means of engagement in the STORCIT-framework. Through photovoice and digital storytelling, participants gather visual materials to translate an experience into a narrative that has been often overlooked at. Under the right conditions, these narrative methods have demonstrated their effectiveness in raising the voices of underrepresented groups, and establishing social change (Liebenberg, 2018; Moutafidou and Bratitsis, 2018). The application of these narrative methods in CS is underexplored, although rapidly evolving in the field as a way to establish dialogue between science, society and policy (Richter et al., 2019).

The main aim of this article is to present and reflect on this framework for making citizen science more inclusive. To this end, the STORCIT-framework was pilot trialed in the "Climate Stories" project which aimed at empowering the voices of young people in the climate debate. Young people, specifically youngsters with a diverse background under 18 years old, are often under-engaged in the climate change dialogue and overlooked as agents of change (Trott, 2019). Through two small-scale studies in Hasselt (located in the Flanders Region, Belgium) and Brussels (Brussels-Capital Region, Belgium) around 50 young people with diverse backgrounds were involved and recorded their experiences about the changing climate.

The next section draws out inclusive approaches in CS research, and photovoice and (digital) storytelling which act as main means of engagement. This is followed by the method section which describes the study setting, the strategies for participant recruitment and the STORCIT-framework. Based upon the principles of CS and PAR, STORCIT is implemented through five phases: i) setting the scene, ii) generating knowledge and learning, iii) sharing personal narratives iv) developing stories, and v) exhibiting to the public. The results section presents the main experienced challenges, limitations, and gains of the framework. In the context of CS research, practitioners are encouraged to explore and further adapt this framework to other (justice) domains and involve other underrepresented groups. Therefore, specific recommendations are formulated in the discussion section, and which might be particularly interesting for CS practitioners who wish to stimulate inclusive dialogue and social change.

## 1.1 Towards inclusive citizen science

CS stands for public participation in scientific research, in which participants contribute to the research process across a wide range of fields (Bonney, 1996). With varying degrees of participation, the interaction in the research process can occur in multiple stages, from defining the research question to sharing evidence-based results (Shirk et al., 2012). Originally, Bonney's definition of CS emphasized the role of citizen scientists as data collectors, rather than as full participants in the research process. In this perspective, large-volume observations are gathered to serve the objectives of the scientific enterprise, rather than the co-creation of knowledge with society (Cooper and Lewenstein, 2016). A more democratic definition of CS was earlier introduced by Irwin to represent a multitude of ways in which the public can involve in science (Irwin, 1995). From this latter point of view, citizen scientists have a meaningful role in the project, and both researchers and participants benefit from taking part (cfr. ECSA, 2015).

While most CS projects today tend to be contributory in nature (Land-Zandstra et al., 2021), participatory CS projects following Irwin's vision are gaining interest. This is particularly the case for environmental-oriented CS projects that involve monitoring of environmental justice, whereby researchers and participants strive to change the power dynamics between science, society and policy (Cooper and Lewenstein, 2016). In participatory approaches, CS can be deployed with an action-oriented framework, e.g., with behavior change frameworks, public interventions aimed at raising further awareness or policy change, hands-on stewardship actions at the local level, *etc.* (Jordan et al., 2019; Coulson et al., 2021). In these projects, opportunities for broad participation are often supported by everyday digital devices, such as smartphones, to gather and evaluate data (Burke, 2006). Citizens can also count on open, low-cost technologies and do-it-yourself (DIY) kits to measures issues that affect them (Gabrys, 2019). These data measurements are often gathered and made accessible via apps or web dashboards, e.g., for air quality through the sensor.community[1]. These advancements of information and communication technologies (ICTs) have certainly enabled a democratization of the knowledge production process, with data becoming more and more available (Bonn et al., 2018).

Although CS projects have taken a participatory turn, the degree to which projects are truly participatory or empowering remains under scrutiny (Strasser et al., 2018). CS projects often only reach participants who already hold an interest (and most often have experience) in science, and thus not a broad and varied audience (Segal et al., 2015; Obiorah et al., 2021; Paleco et al., 2021). Yet, if CS truly aims to contribute to the democratization of science, the research design process should be inclusive, flexible, and adaptive in all its stages (Bonney et al., 2016). CS projects may benefit from deploying inclusive approaches, such as overcoming unfamiliar concepts through understandable language and clarifying expectations (Paleco et al., 2021), articulating comprehensible timeframes (Senabre Hidalgo et al., 2021) and anchoring in local contexts (Devine-Wright, 2013). Such translating practices—whether textual or tacit—may ideally be performed in shared physical spaces, such as science shops or FabLabs, as these allow participants to have access to a tangible version of the translation (Senabre Hidalgo et al., 2021). Here, participants can also acquire the ability to configure their own measurements with DIY-technology. Such physical ways of engaging with CS can overcome the high entry point of online platforms (Spiers et al., 2019; Obiorah et al., 2021).

Another way is to deploy visual thinking strategies and art-based methods, such as storytelling, which can contribute to the alignment of participants' interests in CS (Ravetz and Ravetz, 2017). Telling stories can play an important role in bridging the discourses between science and society (Hecker et al., 2018). They can help to humanize science by communicating scientific facts in an engaging and entertaining way. Stories can thus yield various benefits, such as a greater interest and curiosity in science, raised awareness about science, a deeper connection between science and society, and so on Dahlstrom (2021). Storytelling is often used in the fields of science education (Abrahamson, 1998; Alterio and McDrury, 2003) and science communication (Green et al., 2018; Joubert et al., 2019), and also recently in the field of CS. To explore the role of stories in CS, Richter et al. (2019) identified a typology with three main applications. They found that stories can be non-exclusively applied as objectives (something to pursue), tools (something applied), and agents (something causing effects). For instance, Ottinger focusses on the hermeneutic source of stories for making sense of air quality data (Ottinger, 2017), Constant and Roberts (2017) describe how narratives can be used as a tool to perform research evaluation in and Wehn et al. (2021) detail how storytelling can be used to communicate and measure the impact of new environmental policies. To add meaning to CS data, storytelling techniques are also often being deployed in data representation, e.g., Liu, Cranshaw, and Roseway (2020) showcase how air pollution data can be enriched with subjective anecdotes, perceptions and experiences. Although these examples demonstrate that the field is developing, more systematic research is needed to investigate the multifunctional nature of storytelling in CS. In this regard, this article explores how storytelling can make CS projects inclusive.

## 1.2 Participatory storytelling for social change

Telling stories is an intrinsic human characteristic and evolutionary skill that has been refined over thousands of years (Gottschall, 2013). Throughout history, storytelling has evolved from visual to oral to written, and most recently from analogue to digital formats. Although formats have changed, telling and sharing a story is a universal way to make meaning and sense of life (Straub, 2005). People communicate by telling stories and these stories pass on through history to educate or entertain, or to preserve cultural identity. In narrative communication, storytelling is defined as "*the act of sharing information through a narrative*" (Dahlstrom, 2021, p.2), whereby a narrative tells someone's experience of something. Although various features determine a narrative (Bruner, 2009), a narrative will most often describe a sequence of events with a cause-and-effect relationship in a certain time frame with a set of characters (Dahlstrom, 2014).

By telling stories, people can also speak up and be heard. It provides them the opportunity to share their story and make their voice count. In PAR, storytelling is often used as an instrument to give voice to a certain group (de Jager et al., 2017). Typically, participatory approaches represent "*a counter-hegemonic approach to knowledge production*", whereby researchers recognize the plurality of knowledges and especially of those who have been systematically excluded (Kindon et al., 2007, p.9). Although PAR leaves room for interpretation, at its core, a minimum threshold of genuine participation, tangible action and scientific research should be present (Chevalier and Buckles, 2019). Combining these essential elements, through a cyclic process of action and reflection, can lead to social change and the construction of theory (Fisher and Ball, 2003). This societal change is a deep commitment of PAR, whereby the collected insights into real-life situations can help to address identified concerns and result in effective problem solving.

The most common methods in PAR focus on dialogue, storytelling and collective action (Kindon et al., 2007). In this regard, photovoice and digital storytelling have been employed in various settings to democratize the research process and drive social change, e.g., to examine men's care responsibilities and living conditions in low-income contexts (Tarrant and Hughes, 2020), with young people as agents of change in the climate debate (Trott,

1 https://sensor.community/en/

2019; Finnegan, 2022), with indigenous communities to map out decolonization (Sium and Ritskes, 2013), *etc.* More applied initiatives of these methods, linked to the specific theme of this article, are for instance Young Reporters for the Environment[2] and Voices of Youth[3] which engage young people in the climate debate by exchanging stories, blogs, poems, *etc.* These examples showcase that storytelling methods are highly appropriate to use with underrepresented groups. Participants can express themselves in their own (visual) language and share a story that has often been overlooked at or shared in traditional media (Costera Meijer, 2009). These stories can be positioned as "counter-narratives", *versus* the single or dominant narratives, that may challenge certain stereotypes (Delgado, 1989). Sharing stories can contribute to social change, both on individual, interpersonal and community levels of analysis, with diverse outcomes, e.g., building trust, cultivating norms, generating emotional connections, *etc.* (Winskell and Enger, 2014).

In the set-up of these research methods, three phases are often included, i.e., collection of narrative data, collective interpretation and dissemination of the results (Liebenberg, 2018). Specifically, with the photovoice method, participants are provided with (digital) cameras to capture narrative data of their lives in order to act as recorders and potential catalysts for change (Wang and Burris, 1997). Before they collect data individually or as a group, consensus is reached about the research topic among the participants and researchers. This is an important step in facilitating meaningful engagement and scoping of the research track. The participants are also informed about photography essentials and fieldwork ethics. In a next step, the collected (digital) photographs are used during group discussions to reflect about individual or collective strengths and concerns. A critical dialogue is promoted during these sessions for collecting insights about people's experiences that have been overlooked, rejected or silenced (Singhal et al., 2007). In a final step, the collected narratives are disseminated with the wider community to promote dialogue and eventual social change, e.g., through an exhibition or by translating the findings into policy recommendations (Wang et al., 2000). Photovoice is being used for various applications, often with adaptations to the method according to the specific settings (Naranjo-Bock, 2012). However, Sitter argues that when photovoice is being guided by PAR, certain core attributes should be inherent to the processes, i.e., the positionalities of researchers who intervene as insiders or outsiders, a high decision-making power of the participants, and sufficient time to develop trust (Sitter, 2017).

In the same logic as photovoice, digital storytelling has been used across a wide range of social and environmental issues, such as environmental justice, health services (Gray, 2009), *etc.* In the tradition of Joe Lambert, the founder of the StoryCenter, digital stories are powerful instruments "*to help building a just and healthy world*" (StoryCenter, 2023). In their practice, they define digital stories in a non-elusive way through several characteristics. In brief, it is a personal, experiential narrative on a particular (emotional) subject with a restrained length and design. The digital stories tend to use still images in combination with sound effects and the recorded voice of the storyteller (Lambert and Hessler, 2018). Like photovoice, digital stories are created through a set of workshops, which usually last for three full days and with a small number of participants (5–10) (Gladstone and Stasiulis, 2019). The workshop process includes the necessary time for writing and revising a script, selecting images, and getting acquainted with video-editing software. Story circles, or talking circles, are at the heart of these workshops (Lambert and Hessler, 2018). They provide a safe space for hearing and reflecting about each other's stories, whereby feedback can help to iterate the story. At the end of the process, a final event, such as an exhibition or video screening is organized whereby the stories are presented with some additional comments about the storyteller's experiences and efforts.

In the next section, a framework is presented for using storytelling methods in CS for including underrepresented groups.

## 2 Methods

This section presents "STORCIT", a new framework developed by the article's authors to make citizen science inclusive through storytelling methods. The main objective of this framework is to include the voices of underrepresented groups through stories in which CS data and knowledge are embedded. The STORCIT-framework exists of five implementation phases: i) setting the scene, ii) generating knowledge and learning, iii) sharing personal narratives iv) developing stories, and v) exhibiting to the public.

This framework was pilot trialed in the project "Climate Stories" with two small-scale studies in Hasselt and Brussels. This project was conducted from June 2021 till February 2022, with an average duration of 3 months per pilot, and focused on stories that reflected on the changing climate. Due to the COVID-19 health measures in force at that time, a pragmatic approach was taken to set up the study (e.g., shortening or postponing of activities, smaller group of participants, *etc.*). At the end of the project, a short questionnaire with five questions was distributed among the participants to evaluate the research process. This evaluated their knowledge gain, attitudes towards climate change, and their intention to develop a story in the near future.

The pilot studies, the strategies for participant recruitment and the STORCIT-framework are described in the following sections.

### 2.1 The pilot studies

The pilot studies took place in Hasselt and Brussels. These two regions were selected for their diversity in population figures, the context-specific challenges, and the local expertise of the partners.

The first pilot took place in the summer season of 2021 in Hasselt. Hasselt is the regional capital of the Province of Limburg and counts a population of approximately 80.000 inhabitants. Around 24% of the population has a foreign background (Hasselt, 2022) and 11.5% is at risk of poverty or social inclusion in the Province of Limburg (STATBEL, 2023). Certain areas in the province are highly industrialized, such as Hasselt and Genk, with scrap processing companies and steel factories. The project partners involved in this pilot study were a center of expertise on inclusion, participation, and diversity (UCLL), and a professional youth-

2 https://www.goodplanet.be/nl/yre-nl/
3 https://www.voicesofyouth.org/

service supporting vulnerable young people (Habbekrats vzw). The pilot also received operational support, i.e., facilitation and space, from the LUCA School of Arts, the City of Hasselt, and the University of Hasselt.

The second pilot took place in the winter season of 2021 in Brussels. Brussels, officially the Brussels-Capital-Region, counts a population of approximately 1,2 million inhabitants (STATBEL, 2022). Around 40% of the population has a foreign background and 38.8% is at risk of poverty or social exclusion (STATBEL, 2023). Overall, Brussels is not performing well in meeting the air quality standards of the World Health Organization and is ranked among the top ten cities with the worst health impact in Europe (Khomenko et al., 2021). The dispersion of socio-economical classes in Brussels shows that lower classes live in more densely populated areas and have less access to green space. As a consequence, socially vulnerable groups are increasingly exposed to environmental elements with a negative impact on health (Noel et al., 2020). The project partners involved in this pilot study were a research group in media, innovation, and technology with expertise on CS and PAR (Vrije Universiteit Brussel), a university college dedicated to art and design with expertise on storytelling and DIY-sensing techniques (LUCA School of Arts), and a non-profit organization specialized in digital skills development of vulnerable groups, including youth programmes on digital storytelling (Maks vzw).

## 2.2 The participants

The recruitment of participants occurred through a partner-led approach; Habbekrats vzw led the efforts in Hasselt and Maks vzw for Brussels. A promotional video was developed to engage participants and communicated through social media, newsletters, and mailing lists. Finally, a total of 10 participants in Hasselt and 42 participants in Brussels signed up.

In Hasselt, the pilot was organized as part of an informal learning program of Habbekrats vzw whereby youngsters are invited to go out and explore the city. The age deviated from 10 to 20 years old (with one group of 10–14 years old, and another of 16–20 years old) and all with a migrant background. In Brussels, a secondary school subscribed through Maks vzw for organizing the pilot during their STEM-courses. This secondary school implements a policy aimed at equal educational opportunities to overcome educational disadvantage of underprivileged native and immigrant pupils. 57% of the school population speaks a different native language at home than the language of instruction, and about 60% receives an educational allowance (Overheid, 2022). The average age of the participating group was 14–15 years old, 44% female, and most of them had a migrant background (around 90%).

Prior to the participation in the pilot studies, all minors were informed about the set-up of the study. In agreement with the General Data Protection Regulation, parental consent was attained through a privacy statement and consent form.

## 2.3 The STORCIT-framework

Based on the principles of CS and PAR, the STORCIT-framework involves five consecutive phases to include the voices of underrepresented groups (Figure 1). In all phases, participatory strategies are applied to engage participants in the research process. The first phases focus on research through data collection and analysis, while the latter phases work towards action for social change by developing and sharing stories. In the pilot studies, each phase consisted of one or multiple activities, which lasted on average 2 hours with the support of two or more moderators.

In the first phase, the research theme is identified, as well as an exploratory introduction to the theme. The objective is to collaboratively define the scope of the research, kick-start the project and spark interest and curiosity. In the pilot studies, the main applied activities consisted of thematic field visits, exploration of CS databases, and interactive presentations.

During the second phase, participants are generating knowledge and learning about the research theme. The objective is to collect observations and evidence, analyze the data, and stimulate reflection. In the pilot studies, the main activities for generating knowledge and learning were DIY-sensing, photovoice, and a participatory analysis of the collected photographs and sensor readings.

In the third phase, participants are invited to develop a personal narrative related to the insights that were gained on the research theme in phase one and two. This personal narrative is iteratively developed through the organization of story circles. During a story circle, one participant reads the personal narrative and others listen. In a second iteration, the participant progresses from reading to telling their narrative, which is richer in its performance.

During the fourth phase, participants are invited to collaboratively translate their narratives into a creative format. Stories can be developed with photos, images, video, art supplies, and so on. In the pilot studies, this resulted into the creation of digital stories, photography series and creative slogans.

In the final phase, the objective is to share the stories of the participants with the wider community. In the pilot studies, it was

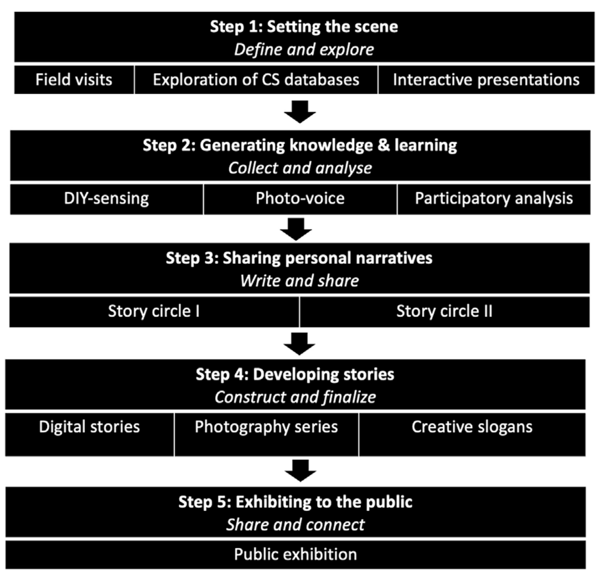


FIGURE 1
STORCIT–Framework for making citizen science inclusive with storytelling.

FIGURE 2
Air quality lens (De Greve et al., 2022).

FIGURE 3
Photograph with a green and blue filter applied by the air quality lens. The air quality is good (De Greve et al., 2022).

opted to organize an exhibition to display the stories. Exhibitions help to raise awareness about the issue, enable community members to rethink the issues from their perspective, and serve as a catalyst for broader social change.

### 2.3.1 Setting the scene

In the pilot study of Hasselt, a brainstorm session about climate change was organized with the participants to define the research theme in a collaborative way. The themes of water, air, heat stress, biodiversity, and circular waste streams were identified, and the participants picked the one that they felt the most enthusiastic about. During the kick-start of the project, three introductory field visits were organized to gain some real-world learning about a particular theme, i.e., a visit to a circular hub, a visit to a local stream to measure water quality together with a CS lab, and a photography workshop. This was complemented with informative presentations about air quality and a quiz about climate change. The participants also explored an online map with air quality measurements collected by citizens from their region. Due to time and financial constraints, it was not possible to explore every theme in depth.

Based on the practical experiences of the pilot in Hasselt, it was collaboratively decided to solely focus on the theme of air quality for the pilot of Brussels. The participants found this theme to be the most interesting, as they wanted to learn how to build the air quality lens. An interactive presentation was organized by the research partners to inform the participants about the sources of pollution, its potential health impacts, and the direct effects of the weather on air quality. Midway the presentation, the participants were invited to look for pollution hotspots in Europe through an online mapping tool. At the end of the presentation, the participants brainstormed about their contributions to good or bad air quality with the help of post-its. In preparation of the next phase, they also received some photography tips and ethical guidelines on paper on how to take good pictures.

### 2.3.2 Generating knowledge and learning

In the second phase, a workshop was organized in both pilots where the participants received a kit to assemble an air quality lens (De Greve et al., 2022). This air quality lens (Figure 2) can alter photographs based on real-time data from nearby air quality sensors of the network Sensor. community[4]. The lens can be placed in front of a smartphone or point-and-shoot camera and will apply a blue or green filter when the air quality is good (Figure 3), and a red or purple filter when the air quality is bad. After the assembly process by the participants, the photovoice method was explained and a walking tour in the city was organized with five short stops. During the walk, the participants photographed landscapes and sources related to air quality, sometimes with or without the lens. They also recorded their experiences through pen and paper. At every stop a short show-and-tell was organized to collaboratively analyze and discuss the photographs. Reflections were made about the sources of air pollution, the effects of the weather, and the link between the source and the color filter on the photographs. Besides the air quality lens, a temperature sensor was also used in the pilot of Hasselt. A dedicated walking tour was organized with these sensing devices to reflect about heat stress in the city.

### 2.3.3 Sharing personal narratives

In this phase, two story circles were organized with three moderators per session, each session lasting approximately 2 h. Maks vzw, specialized in digital storytelling, moderated these

4 https://sensor.community/en/

FIGURE 4
Story circle I - writing the narrative. (Photo by Carina Veeckman).

FIGURE 5
Developing a digital story on the tablet. (Photo by Carina Veeckman).

sessions and gave prior training to the other moderators. During these sessions, the collected photographs from the previous phase were printed or digitally archived. With the help of these photographs, the participants formulated a narrative and reflected about the main message they wanted to share. The moderators guided the participants by asking questions on why they took that photograph and what it meant to them: "What do you **S**ee?", "What was **H**appening here?", "Does this happen in **O**ur community?", "**W**hy is this a problem? and "What can we **D**o about it?". These questions are part of the SHOWeD technique of Shaffer (1983) and help to promote self-awareness, sensitivity and self-reliance in problem solving. After writing down their narratives on paper (Figure 4), they were presented within a small group with respectively four to six participants. These presentations helped the participants to finetune their storyline.

### 2.3.4 Developing stories

The stories were developed in different creative formats. The participants in Hasselt translated their narratives into creative slogans and artwork on big posters, while in Brussels a digital format was preferred. The choice of format was influenced by the participants' preferences for a simple or more elaborated format, the context (i.e., an informal *versus* formal learning environment) and the age difference between the participants; with younger participants opting for tangible artwork. For the digital format, the participants translated their narratives with the help of tablets and video editing software (Figure 5). Therefore, the participants could use their photographs from phase two or royalty-free images which they searched online. The participants also recorded their own voiceover with the help of a microphone and added it to their videos. Sound and video effects were added in the final editing stage. Each digital story lasted approximately between 30 and 90 s.

### 2.3.5 Exhibiting to the public

In Hasselt, due to COVID-19 regulatory measures at the time, it was not possible to organize an indoor exhibition for the public. Instead, the creative slogans, art works, and photography series were exhibited on the front windows of the town hall of the City of Hasselt for a 2-months period (Figure 6). In Brussels, an exhibition was organized in a gallery space, in collaboration with bachelor students of LUCA School of Arts. The students helped to set up the exhibition space and some of them also participated by sharing their own personal narrative about climate change through an interactive art installation. The digital stories, 23 in total, were exhibited through three old television screens and a headset to create an intimate atmosphere (Figure 7). The air quality lens was also displayed, as well as a selection of the photographs from phase two. This exhibition lasted for 3 days. A press release was sent out to promote the event and local policymakers in the domain of sustainable development received a personal invitation.

## 3 Results

In the following sections, the main experienced challenges, limitations, and gains of the framework are described. Based on core principles of CS and PAR, the findings are grouped into the themes of participation, research, and actions for social change.

### 3.1 Participation: youth as agents of change

In both pilot studies, the local partnership successfully resulted in a mixed group of young people with a diverse background. In Hasselt, the youngsters voluntarily signed up via the informal learning activities organised by Habbekrats vzw, while in Brussels the study was part of a formal learning setting. Although the intention was to organize both pilot studies in an informal learning setting, whereby participants could voluntarily sign up out of interest, this was not possible in Brussels. The restrictive COVID-19 health measures at that specific time resulted in a low sign-up rate. For this reason, Maks vzw reached out to a high school in a multicultural neighborhood in the capital. Although it was not


FIGURE 6
Exhibition of the photography series and creative slogans in Hasselt (Photo by Jessica Schoffelen).


FIGURE 7
Exhibition of the digital stories in Brussels (photo by *Petar Veljačić*).

investigated as such, it can be argued that participants had different motivations to participate in the research process.

During the pilot studies, the youngsters were deeply engaged in the research process, whereby they could define the research theme, collect and analyze the data, and share an outcome. The workshop moderators only intervened in the research process in case of financial and/or practical time constraints, or if support was needed. As such, based on the practical experience of the pilot study in Hasselt, it was collaboratively decided to focus on one theme instead of many in Brussels. In addition, moderators supported the participatory analysis by asking and rephrasing questions, and by providing exploratory information for the collected findings. The moderators also made the final selection of the photography series exhibited at the event in Brussels based on the top-three voting of "best pictures" by the participants. Overall, a high level of engagement was thus established in the research process, with participants having significant freedom to create their narratives.

The pilots' duration of 3 months, with five to six workshops in total, demonstrated to be effective for establishing trust between the moderators and the participants. On the other hand, this timeframe caused a loss of knowledge that was build up during phase one and three. During the narrative development, moderators noticed that the participants had to be reminded about, e.g., the main sources of air pollution, or its causes and effects.

## 3.2 Generating knowledge and learning about the changing climate

In both pilot studies, easy-to-use instruments were opted for data collection and analysis of the changing climate. The main instrument was an air quality lens that helps to visualize air quality data captured by low-cost particulate sensors of the sensor. community[5]. This lens supports narration of the data through a color overlay on photographs. The air quality lens was used during a walking tour with several stops, in combination with a digital camera or smartphone for taking photographs. The walks with the lens took place during winter, with mostly open skies and strong winds, and thus an overall good air quality. This resulted in mostly green overlays on the photographs. However, this contrasted with the experience of the participants when they wanted to photograph

5 https://sensor.community/en/

specific objects, e.g., traffic jams, busses, trucks, chimneys, *etc.* This caused a misperception among the participants that the air quality is always good, although they clearly identified sources that contribute to bad air quality. During the show-and-tell stops, the workshop moderators reminded the participants about the main takeaways from the training in phase one in order to avoid misinterpretation of the findings, i.e., the weather effects on air quality and the spatial distribution of the sensors. Although the air quality lens made the data more visually accessible, the interpretative processes still needed support and critical questioning from the workshop moderators.

When the participants wrote and shared their narratives, collaborative analysis was mixed with individual problem solving. It was up to the participants to choose whether to work independently or in pairs; 6 in 10 participants preferred to work in pairs. Working in pairs sparked creativity and created a safe space to share their narratives. For instance, this sparked the idea to compare the air quality between Belgium and their countries of origin. Those working individually were satisfied to work at their own time and level, and shared their narrative once they were finished.

During the analysis, the workshop moderators noticed that for most participants it was difficult to translate the findings into a personal narrative. Intuitively, participants tended to write a factual narrative in an educational manner, rather than from their personal experiences. The moderators provided support during the story circles by asking questions through the SHOWeD technique, e.g., about the ways they feel affected by the changing climate, the main message of their stories and its central emotions, *etc.* Through these discussions, the participants succeeded in finding a personal storyline with often a clear call-to-action at the end of their narrative, e.g., "*it is our city, our world, we have to act now*", "*everyone struggles with it, and we soon hope for a better air quality*", "*we need to protest against it, and let the government take measurements*".

## 3.3 Action for social change

Through the exhibitions organized in phase five, the participants were able to have informal conversations with community members about their stories in a setting outside of their familiar context. In Hasselt, the resulting stories were displayed in public space, without context. Through the deployment of street art strategies, these posters were oriented at any passer-by that opportunistically engaged with the information. In Brussels, the exhibition took place inside a public institution for the arts, in a semi-public space. The digital stories were surrounded by students' artworks on the topic of climate change, which provided additional context.

Through these exhibitions, the participants learnt how to communicate their voice and claim their equal participation in society. While some participants were a bit nervous about hearing their own voices in a public space, others found it neutral to positive. Half of the participants also acknowledged to have learnt something new: taking photographs, interpreting the findings, presenting a narrative for a group, editing a video, recording audio, and so on. A third of the participants in Brussels acknowledged that they would love to develop another story in the future.

A federal policy maker and an educational organization in sustainability for youngsters passed by the event in Brussels. Some of the participants were encouraged by these stakeholders to also share their story through their dissemination channels and enter a competition. The developed stories are also shared through the (social media) channels of the involved partners in the consortium, and through an online Vimeo channel[6] of Maks vzw. As such, these stories continue to exist and retain attention to young people as agents of change.

# 4 Discussion

This article presents a novel framework for including the voices of underrepresented groups in CS through storytelling methods. The framework was specifically designed for the "Climate Stories" project that aimed to empower vulnerable youth in the climate debate. The implemented framework, designed on the core principles of PAR and CS, helped to empower the youngsters in various ways. They were deeply involved in the research process and could define the research topic, collaborate in the data collection and analysis, and share their personal narratives. Secondly, capacities were built to raise their voice and speak for themselves through storytelling methods, and finally, a collective action was taken to disseminate the research results to a broader audience.

In the context of CS research, practitioners are encouraged to validate this framework in other (justice) domains (e.g., health, mobility, food, *etc.*) and with other vulnerable target groups (e.g., older people, migrants, *etc.*). Thereby, it is advised to fit the technology formats and activities with the (digital) profile of the target group. The choice of technology should be in line with the participants' demographics, affordability and access, and fitness for purpose (Mazumdar et al., 2018), and in turn, this might influence the level of engagement in the research study (Sanabria-Z et al., 2022). Furthermore, a set of potential activities is described in the framework, but these are not set in stone and can be modified to suit the research context. Other activities that might support the objectives in the phases are for instance the usage of mobile applications to collect narrative data (cfr. The "Our Voice" method in King et al. (2021)), or other types of action-oriented activities such as family or community action projects to support the sustainability in the area (cfr. Trott, 2019).

During the implementation of the framework, core attributes of PAR were duly considered, i.e., the positionality of the researcher, the decision-making power of the participants, and sufficient time for building trust (Sitter, 2017). Based on the experiences from the workshop moderators, some suggestions for improvement were found.

- First, although participants received training in phase one, several participants were experiencing difficulties for interpreting the data in phase three. Without the intervening of workshop moderators this could have led to the misconception that most of the time our air is clean.

6 https://vimeo.com/maksvzw, specific example: https://vimeo.com/721386265 (The story of Ruby & Lana).

Therefore, in agreement with Ottinger (2017), it is recommended that meaning-making of data should still be a collaborative process between participants and workshop moderators, or with thematic (data) experts. To enhance independent learning and critical thinking skills, it is recommended to build in extra training for the data collection activities in phase two. Another recommendation is to look into resources which can support argumentation skills in phase three, e.g., activities that invite participants to understand and practice scientifically valid ways of arguing, formulating arguments consisting of claims with either data or warrants (Osborne et al., 2001), fact-checking workshops, *etc.* These recommendations can help to overcome "narrative mismatches", i.e., stories not matching with the available data, and give due credibility to their stories.

- Second, workshop moderators found that participants were initially struggling to balance science-based facts with their personal views on climate change. Intuitively, they wrote a fact-based narrative on climate change, without including a first-person perspective. Martinez-Conde et al. (2019) investigated how the brain works when engaging with scientific storytelling and stress that a story should not only engage people's intellect, but also their feelings. If there is little interest in a story, there is probably a disconnect between the scientific content and its emotional impact. Therefore, a correct balance should be sought between deductive and inductive reasoning in the story circles in phase three, i.e., between generalizable facts and the expression of emotion and values. To support this, additional training on the photovoice methodology and expert help in making data meaningful is recommended in phase three of the framework.
- Last, it appeared that the total length of the research, i.e., five to six workshops spread over 3 months, caused a loss of knowledge between the first and last phases. Some research projects with storytelling methods continue over many months or years, with photovoice focusing on various aspects of participants' lives (cfr.Wilson et al., 2007). In this case, the research focused only one perspective related to climate change, namely, the capturing of data in a city context. Since the data insights gathered in the first phases are of importance for the latter phases, it is recommended to opt for a more regular interval of reflection and action when handling CS data.

A question for future research is whether this framework resulted in any longstanding impacts. The results showed that the participants acquired additional skills and knowledge related to the research topic, however, it is unclear if this knowledge and active engagement retained after the Climate Stories project. Investigating the long-term impacts of these projects is thus of crucial importance to understand the transformative potential towards building testimonial justice and inclusive dialogue between science, society, and policy.

Finally, in terms of further theory building and practice, the STORCIT-framework provides an additional approach for CS practitioners who wish to engage diverse audiences in multiple stages of their research. In this way, STORCIT demonstrated that combining CS and storytelling methods is showcasing potential for engaging underrepresented groups and establishing inclusive dialogue between science, society, and policy. Although not all CS projects are intended to democratize science or to lead to social justice outcomes (Bonney et al., 2016), a strong link between science, society and policy will only be reached when a genuine two-way collaboration is established between researchers and participants. To further advance the field, CS practitioners are thus encouraged to use and adapt this framework to build inclusive science for the benefit of all.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Materials, further inquiries can be directed to the corresponding author.

## Ethics statement

Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the minor(s)' legal guardian/ next of kin for the publication of any potentially identifiable images or data included in this article.

## Author contributions

CV was responsible for the project administration and funding acquisition. CV and SC contributed to the conception and design of the study. CV conceptualized the method part and performed the analysis. CV wrote the draft of the manuscript. CV revised the manuscript. SC contributed to section 1.1. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# Bridging citizen science and science communication: insights from a global study of science communicators

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A large study of science communicators around the world was conducted as part of the GlobalSCAPE research project. All participants in the study indicated some level of science communication experience, with more than 11% choosing "citizen scientist" as one of their identities. This paper provides an overview of how science communication and citizen science are two independent fields of research and practice that have opportunities for overlap and mutually beneficial outcomes, particularly in terms of the practices of those working in areas of public engagement with science. In addition, qualitative results are presented regarding the experience of being a science communicator for those who identified as citizen scientists. The paper also showcases the first empirical insights from the GlobalSCAPE project, which exemplifies how international research collaborations can be used to explore the challenges and opportunities faced by those individuals working in science communication and citizen science.

KEYWORDS

**science communication, citizen science, Science with and for Society (SwafS), GlobalSCAPE, research projects, correlation analysis, identity, European Commission**

## 1 Introduction

Citizen science and science communication have become increasingly important fields of research and practice in recent years, as society faces unprecedented challenges that require new techniques and tools grounded in scientific understanding (Bucchi, 2017; Ryan et al., 2018; Skarzauskiene and Mačiulienė, 2021). Climate change, emerging infectious diseases, and rapidly changing new technologies are all challenges that are global in scale and benefit from the involvement of citizens as partners in research and innovation (Wamsler and Brink, 2014; Meentemeyer et al., 2015; Cappa et al., 2022). Citizen science is an approach to scientific research that involves members of the public in the research process, including data collection, analysis, and interpretation. Science communication, on the other hand, is the practice of sharing scientific information with non-experts and engaging public audiences in discussion and debate about scientific topics.

The need for effective citizen science and science communication has never been greater, with the COVID-19 pandemic highlighting the importance of collaboration and the incorporation of diverse perspectives as society began to seek accurate and timely information to inform their decisions (Andrews-Fearon et al., 2020; Katapally, 2020; Massarani et al., 2020). Together, citizen science and science communication can play a critical role in giving citizens greater access to scientific information and the ability to participate in scientific decision-making processes. However, understanding the relationship between these two fields, and the role of those who bridge the gap between them, is crucial to maximising their impact and addressing their shared challenges.

## 1.1 Citizen science: public participation in science

Citizen science can be a theoretical or practical approach to research as well as being a field of research in its own right (Kullenberg and Kasperowski, 2016; Heigl et al., 2019; Roche et al., 2020). Citizen science has long been considered to hold vast potential for helping society (Irwin, 1995; Lewenstein, 2022) and, as well as being a distinct field of enquiry (Jordan et al., 2015), has increasing prominence in areas such as astronomy, ecology, meteorology, and medicine (Lewandowski et al., 2017). While the term "citizen science" broadly applies to scientific research that involves people who do not identify as professional scientists (Bonney et al., 2009; Silvertown, 2009), the theoretical context of the individual terms "citizen" and "science" can vary greatly depending on a range of factors and circumstances (Eitzel et al., 2017; Haklay et al., 2021). Although the issue of terminology has been present in the field of citizen science since the beginning, it has been hotly debated recently with discussions held at the major science communication and citizen science conferences in 2023 (Roche et al., 2023). One of the central issues of the terminology debate—the distinction between citizen science and community science and how the "citizen" term can be insensitive to marginalised communities (Ellwood et al., 2023; Lin Hunter et al., 2023)—culminated in the US-based but globally-reaching Citizen Science Association changing its name to "the Association for Advancing Participatory Sciences". While there is no doubt that inclusion needs to be improved in the field (Cooper et al., 2021), some citizen science scholars have suggested that the field can be made more inclusive without resorting to abandoning a term that has gradually been gaining in scientific and political credibility in recent years (Haklay, 2023). These debates have bolstered the idea that communication and engagement are central to the future of citizen science.

## 1.2 Science communication: engaging audiences in dialogue and debate

Effective communication of scientific findings to public audiences serves to enhance public trust in science and facilitate wider public engagement in scientific research (Fischhoff and Scheufele, 2013; Schäfer, 2016; Achiam et al., 2022). Science communication is not just the "communication of knowledge from scientific experts to public audiences" (Bultitude, 2011, p. 32), but is instead a two-way exchange with public audiences, as well as a field of research and practice in its own right (Burns et al., 2003; Trench, 2008). In recent years, in tandem with the challenge of communicating science in a "post-truth society" (Iyengar and Massey, 2019, p.7656), the field of science communication has grown substantially as a discipline taught in higher education institutions around the world (Massarani et al., In Review), amid growing calls to incorporate it more substantially into science education (Bubela et al., 2009; Mercer-Mapstone and Kuchel, 2017).

Responsible science communication is as important as ever (Scheufele and Krause, 2019; Howell and Brossard, 2021; Hyland-Wood et al., 2021) with a number of prominent challenges emerging in the field. There are disparate views among scientists on the relationship between science communication and socio-political impacts and what science communication can achieve (Scheufele, 2014; Fähnrich, 2017; Besley et al., 2018; Fähnrich et al., 2020). For example, while "historically science communication has been predicated on the assumption that ignorance is the basis of a lack of societal support for various issues in science and technology"—the so-called 'deficit model' of science communication (Simis et al., 2016, p. 401)—research has demonstrated that science communication is far more complex than the deficit model would suggest, with models of dialogue and participation being integral to the responsible public communication of science (Davies, 2008; Horst and Michael, 2011). The motivation for science communication can sometimes be conflated with objectives spanning from education to promotion and are often lacking in meaningful evaluation (Jensen, 2014; Weingart and Joubert, 2019). The people involved in science communication are often based in universities and research or education organisations and can be researchers, scientists, communication professionals, educators, students, volunteers, or freelancers, among other roles (Davies and Horst, 2016; Weingart and Guenther, 2016). The few studies that have explored the people involved in science communication have demonstrated the richness of the topic and how the broad range of backgrounds and experiences of the people involved make it ripe for further study, especially given how the availability and accessibility of funding and support for science communicators can greatly affect their work (Koivumäki and Wilkinson, 2020; Besley et al., 2021).

## 1.3 Potential synergies between citizen science and science communication

Citizen science can benefit from effective science communication. Clear communication of the goals and outcomes of citizen science projects can help to increase participation rates, especially among groups that are traditionally underrepresented in science (Bonney et al., 2009; Dickinson et al., 2012; Gunnell et al., 2021). Effective communication can also help to ensure that the data collected by citizen scientists are accurate and reliable (Kosmala et al., 2016; Balázs et al., 2021). Ideally, the findings from citizen science projects can be communicated back to the participants and wider public audiences, contributing to a more informed society and a more participatory approach to science (Dickinson et al., 2010; Hecker et al., 2018). Indeed, there is an argument that "communication in citizen science is always science communication" (Wagenknecht et al., 2021, p.1).

Citizen science also has the potential to enhance science communication. By involving public audiences in scientific research, citizen science can provide a platform for public engagement with science that is not always accessible through traditional methods of science communication, offering a way for individuals to contribute to scientific research and to have a stake in the scientific process, leading to greater public ownership of scientific knowledge (Bonney et al., 2016; Gunnell et al., 2021). The collaborative nature of citizen science can also lead to the development of new knowledge and innovative ways to address scientific problems (Haklay, 2013; Vohland et al., 2021). By exploring these potential synergies, it may be possible to develop more effective approaches to science communication that can help to build public trust in science and promote wider public participation in scientific research (Golumbic et al., 2020; Magalhães et al., 2022).

### 1.4 GlobalSCAPE: a global study of science communicators

From 2018–2020, the European Commission, through a funding call in the Science with and for Society (SwafS) pillar of Horizon 2020, the world's largest multinational research funding programme (Abbott, 2020), invited large-scale research proposals to take stock and re-examine the role of science communication (European Commission, 2020; Roche et al., 2021a). This was the first dedicated research funding call (rather than a "Coordination and Support Action") of its size offered by the European Commission for science communication research, and saw a total of eight projects funded (CONCISE, RETHINK, QUEST, TRESCA, NEWSERA, ParCos, ENJOI, and GlobalSCAPE), with an overall investment of almost €10 million (European Commission, 2022; Roche et al., 2023). These "SwafS-19" Projects (as they become known due to being the 19th topic in the final SwafS funding programme) were tasked with bringing together "journalists and science communicators, researchers, civil society groups, industry experts and policymakers," the so-called "quintuple helix" of stakeholders, to "examine issues such as quality of science communication, trust in science, and the mitigation of the spread and impact of misinformation, disinformation and fake news" (European Commission, 2022, p. 2). The NEWSERA project, for example, specifically focused on integrating citizen science and science communication in Europe and demonstrated that citizen science projects often interpret communication as more of dissemination activity without harnessing its potential for deeper engagement (Magalhães et al., 2022; Giardullo et al., 2023).

As the last of the eight SwafS-19 projects to commence from the (to-date) final research funding call from the European Commission in the specific area of science communication research, GlobalSCAPE had a responsibility to extend beyond the "disparate and fragmented" landscape of European science communication (Davies et al., 2021, p. 5) to attempt to take into account the experiences of science communicators around the world. This paper shares some of the first insights from the GlobalSCAPE project, which employed an innovative methodology comprising a longitudinal diary study of science communicators around the world to collect data on the challenges and opportunities they face as they navigate a rapidly changing field. There has been little consideration of the people who work across both citizen science and science communication, and how the experiences of such individuals may be investigated and better understood. The key question this paper seeks to answer is whether projects such as GlobalSCAPE can provide insights into the role of science communicators and if there is any overlap with citizen science. Given that science communication and citizen science can be powerful tools for providing opportunities for engagement with, or participation in, scientific research, together they have vast potential to reach beyond individual scientific disciplines to attract wider public participation in scientific research, address societal challenges, build greater trust between science and society, and promote more democratic science.

## 2 Methods

At the beginning of the GlobalSCAPE study, a baseline survey was developed to understand the backgrounds of potential participants before inviting them to enrol in the full longitudinal diary study. The findings of this paper are based on the data collected from that baseline survey. Ethical approval for the study was granted by a research ethics committee at the coordinating university, Trinity College Dublin.

The baseline survey was developed to include a wide range of profile questions about the science communicators, along with demographic information such as age and gender. It was first piloted with a sample of 23 participants from four continents, recruited by project partners using convenience and purposive sampling (Etikan et al., 2016; Obilor, 2023), to provide feedback on the clarity of the survey questions. The piloting stage included follow-up questions as the participants completed each step in the survey and, based on this feedback, each question and set of response options was tweaked and validated to generate the final version of the questions used in the baseline survey. The questions developed in the baseline survey—including their original versions, the edits and tweaks suggested by participants in the piloting stage, and the final versions of the questions used—are publicly available in the European Commission's open access repository, Open Research Europe (See Jensen et al., 2022). The data gathered from this piloting stage (excluding answers to open-ended questions to ensure data privacy) are also publicly available and can be accessed through Zenodo (See Jensen et al., 2021).

The baseline survey, and the recruitment emails, were made available in nine languages: Arabic, Chinese, English, French, German, Italian, Portuguese, Russian, and Spanish. To ensure the robustness and consistency of the recruitment emails, survey questions, and survey responses, a forward-backward translation methodology was used (Degroot et al., 1994). For each language, two different translators were involved: one translated the text forward from the original language to the target language and the other translator translated the text from the target language back into the original language. Any discrepancies between the forward-backward translated text were then discussed between the translators to find consensus.

After the piloting stage, data collection for the baseline survey was implemented through a campaign to share the survey with science communicators around the world. Once again, convenience and purposive sampling was employed. In addition, however, snowball sampling (Handcock and Gile, 2011) was utilised as the project consortium shared an online version of the survey with their networks who, in turn, made their own referrals to science communicators. The GlobalSCAPE consortium included two universities (Trinity College Dublin and Leiden University), a research company (Qualia Analytics), an academic publishing company (Springer Nature), and two networks—Ecsite, the European network of science centres and museums, which offers the largest annual science engagement conference in Europe (Roche et al., 2018; Mignan and Joubert, 2022), and SciDev.Net, the leading science and technology journalism organisation for global development (Dickson, 2004; Massarani, 2004). Utilising these global networks, invitations were sent to science communicators in November 2021 and the survey was closed at the end of 2022 with over 900 respondents. The majority of participants were from Africa (29%), Europe (25%), and Asia (15%), with smaller levels of participation from North and South America and Oceania.

# 3 Results

## 3.1 Citizen science in global science communication

Relevant aspects of respondents' background and experience with science communication were a key focus of the study. Specifically, respondents were asked, *"Are you involved in communicating about science or research with people who are not scientists or researchers?"* The majority of respondents ($n = 762$, 81.5%) were actively involved in such public communication activities, while a smaller percentage only engaged occasionally ($n = 137$, 14.7%), and 3.9% ($n = 36$) did not engage at all. The key question, *"Do you consider yourself a science communicator?"* garnered 879 responses, with 87% indicating *"Yes"* or *"Sometimes"*. Building on this, the survey asked if people identified with a number of possible labels for their role as science communicators. 1712 responses were obtained from 963 participants. The most common role reported was *scientist or researcher* (n = 342, 35%), followed by *science writer or journalist* (n = 315, 33%), *science teacher or educator* (n = 253, 26%), and *science communication researcher* (n = 196, 20%). Less than 12% (n = 108, 11.2%) identified themselves as a *citizen scientist*. Of the respondents who identified as a *citizen scientist*, most respondents (n = 92, 87.6%) confirmed being actively involved in science communication. A Chi-square test assessing the relationship between gender and citizen scientist identification revealed no statistically significant effect ($X^2(2) = 3.760$, $p = .152$). There was no statistically significant relationship between age band and citizen scientist identification ($X^2(6) = 10.876$, $p = .092$). There was also no difference between those with a university degree (96%; n = 90) and those who did not have a degree (4%; n = 4) among those who indicated identifying as a citizen scientist (n = 94) ($X^2(3) = 0.89$, $p = .829$).

## 3.2 Correlation analysis: citizen scientist and other identities

The correlation between identification as a citizen scientist and other roles like volunteer in science communication, science teacher or educator, science performer, science communication researcher, and scientist or researcher was analysed (Table 1). These variables are discussed below in descending order based on the amount of variance explained by each statistically significant correlation. The strongest correlation identified was between the roles of citizen scientist and volunteer in science communication ($r = 0.209$, $n = 963$, $p < 0.001$). This relationship was statistically significant and accounted for 4.36% of the variance in the sample. This suggests that those who identify as citizen scientists are also likely to engage in voluntary science communication activities, or *vice versa*. The shared role indicates that citizen scientists are proactive in engaging with their communities, often working on a voluntary basis to translate and communicate scientific information.

Next, a significant relationship was found between the roles of citizen scientist and science teacher or educator ($r = 0.141$, $n = 963$, $p < 0.001$), accounting for 1.98% of the variance. This implies that citizen scientists often play an educational role, facilitating understanding of scientific concepts within their communities, or that some science educators and teachers identify as citizen scientists. This could involve informal citizen science education efforts, such as hosting workshops or giving talks, or more formal roles like teaching science in schools or other educational settings. The role of a citizen scientist also showed a significant correlation with that of a science performer ($r = 0.112$, $n = 963$, $p = 0.001$), which explained 1.25% of the variance. Science performers use theatrical or artistic means to communicate science to the public, and this link suggests that some citizen scientists might use similar, non-traditional formats to engage audiences with scientific content. A positive correlation was identified between the roles of citizen scientist and science communication researcher ($r = 0.100$, $n = 963$, $p = 0.002$), accounting for 1.00% of the variance. This suggests that some citizen scientists have research-oriented roles, studying the efficacy and methods of science communication.

Finally, a significant, yet slightly weaker correlation emerged between the roles of citizen scientist and scientist or researcher ($r = 0.097$, $n = 963$, $p = 0.003$), accounting for 0.94% of the variance. This indicates that a fraction of citizen scientists are also professional scientists or researchers, straddling the line between professional scientific investigation and community-based science communication.

## 3.3 Qualitative results: science communicators identifying as citizen scientists

Analysing the experiences of science communicators who identified as citizen scientists in the baseline survey offers rich insights into their multifaceted roles, challenges, and rewards. These individuals play a vital role in translating scientific concepts into digestible information, fostering scientific literacy. A thematic analysis (Braun and Clarke, 2021) was carried out on the responses from the 11.2% of science communicators who identified as citizen

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**TABLE 1 Correlation matrix for science communicator roles. This table demonstrates that in the baseline survey of science communicators (N = 963), the 11.2% who identified as citizen scientists identified with other roles to varying degrees of significance. "Volunteer in science communication" and "Science teacher or educator" were most significant.**

| Correlations | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Role | | Variables | | | | | | | | |
| | | Public engagement professional | Science performer | Volunteer in science communication | Science museum or centre professional | Science communication researcher | Science teacher or educator | Scientist or researcher | Science writer or journalist | Science or research communicator |
| Citizen scientist | Pearson Correlation | −0.010 | .112** | .209** | 0.042 | .100** | .141** | .097** | −0.023 | −0.022 |
| | Sig. (2-tailed) | 0.907 | 0.001 | 0.001 | 0.194 | 0.002 | 0.001 | 0.003 | 0.476 | 0.804 |

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

scientists. This involved coding the responses to an open-ended option in the survey for respondents to give their views on being a professional science communicator (Jensen et al., 2022) and identifying the themes that emerged from those answers in order of frequency (Jensen and Laurie, 2016). Seven key themes emerged: responsibility and engagement, passion for dissemination, continuous learning, simplification and accessibility, creative and contextual communication, perseverance amid challenges, and the fundamental importance of promoting scientific literacy. Examples of these seven main themes, in descending order of frequency mentioned, are presented below.

Responsibility and Engagement. Citizen scientists feel deeply tied to their communities, enhancing their commitment to science communication. They aim to foster dialogue that improves public understanding of science. One respondent said, *"Being able to inform without causing a stir in society."* Another respondent added, *"I think about responsibility when it comes to being a science communicator in the day-to-day experience."*

Passion for Science Dissemination. Respondents frequently highlighted their enthusiasm for science and dedication to sharing it with others. They are driven by the goal of making knowledge about science accessible. One participant encapsulated this view: *"My day-to-day experience as a science communicator is fulfilling. Reaching out and impacting lives is rewarding."*

Continuous Learning. Staying updated on scientific research is crucial to their role. This continuous learning helps them deliver accurate, timely information to public audiences and aids their personal and professional growth. One respondent stated, *"Being updated and knowledgeable about the latest scientific work."*

Distillation and Accessibility. The difficulty of converting complex science into understandable language is a significant challenge but an integral part of their role. They find making scientific knowledge accessible both challenging and fulfilling. A respondent summarised this challenge: *"Transform topics, sometimes complex, into simpler contexts."*

Creative and Contextual Communication. The respondents emphasised the importance of finding effective communication channels and methods that resonate with their audience. This involves creativity and understanding their audience's context. One respondent mentioned, *"Finding different channels to be able to communicate science or engage persons not related to scientific activities, in a way promote citizen science."*

Challenges and Perseverance. Despite their passion, citizen scientists face hurdles like public resistance to scientific findings and underappreciation of their work. One respondent encapsulated these challenges: *"Frustration. In general, [. . .] all the people who refuse to listen to facts or the particularly irritating people who shout 'wrong' or 'fake news' whenever I discuss the science behind complicated socio-political issues with them."*

# 4 Discussion

## 4.1 GlobalSCAPE findings and limitations

The findings offer a detailed examination of individuals who identify as science communicators and citizen scientists, unveiling the intersections and relationships among various roles within the landscape of science communication. Notably, the identification as citizen scientists was found among 11.2% of respondents, indicating that an overlap exists between the fields of science communication and citizen science. The correlational analysis revealed that these individuals are highly likely to engage in other roles, particularly as volunteers in science communication, science teachers or educators, science performers, science communication researchers, and scientists or researchers. While these correlations are statistically significant, they explain only a relatively small percentage of the total variance, implying that the identities and roles within the field of science communication are multifaceted and diverse.

Although previous studies have found links between citizen science and sustainability (Fritz et al., 2019; Fraisl et al., 2020; Skarzauskiene and Mačiulienė, 2021), and citizen science and education (Roche et al., 2020; Kloetzer et al., 2021; Quinnell et al., 2023), GlobalSCAPE is the first large-scale study of its kind to explore the link between science communication and citizen science in terms of the international cadre of science communicators. While an overlap between science communicators who bridge both disciplines was demonstrated, there were also limitations to the study. Although the number of science communicators who chose *citizen scientist* as part of their professional identity in the GlobalSCAPE survey is an interesting insight, the question was a close-ended question that invited participants to select their identities from a predefined list. That list was validated, with the rest of the questions at the piloting stage, but it still somewhat reduced the significance of the response rate compared to if the same number of participants had chosen that option in an open-ended question.

It is also not clear if each of the science communicators identifying as a citizen scientist were following the same definition of what a citizen scientist is. While the forward-backward translation methodology was used to bolster consistency among the different languages, for any high degrees of complexity there remain limitations to how uniform the understanding of the terminology can be in different languages (Ozolins et al., 2020). Although individuals whose practices relate to science are more likely to be clear on citizen science definitions (Roche et al., 2021b), there is still a chance that those identifying as a citizen scientist might be using a different understanding of what constitutes citizen science. While this complicates any extrapolations drawn from their choice, it is also an aspect that is endemic to citizen science research in general, with the complexity and variety of views, perceptions, and understandings of the terms "citizen science" and "citizen scientist" one of the few constants in the field of citizen science (Eitzel et al., 2017; Haklay et al., 2021; Haklay, 2023).

## 4.2 Implications

Science communicators who identify as citizen scientists exhibit a deep sense of responsibility and engagement, driven by a passion for science and a commitment to continuous learning. Despite challenges in translating complex scientific concepts into accessible language and navigating public resistance, their perseverance underscores the importance they place on science communication. This is especially important as citizen science has ample capacity for transdisciplinarity and for integrating the natural, physical, and health sciences with the humanities and social sciences (Pykett et al., 2020; Tauginiene et al., 2020). Citizen science has been highlighted as means of harnessing non-traditional data sources to contribute to the Sustainable Development Goals of the United Nations (Fritz et al., 2019; Fraisl et al., 2020). For the people who bridge citizen science and science communication, there remain obstacles to be overcome. Citizen science does not always give due consideration to the perspective of participants (Phillips et al., 2019), there are enduring challenges with terminology, inclusion, and access to participation (Cooper et al., 2021), and there is even the potential for communities to be exploited under the guise of citizen science (Roche and Davis, 2017; Roy and Edwards, 2019). However, despite these hurdles, it is the vast potential of citizen science to reach beyond individual disciplines and attract wider public participation in scientific research that could be most beneficial in helping to tackle societal challenges.

The implication of these findings is that training and support mechanisms for these citizen scientists should prioritise skills in translating complex concepts, managing public resistance, and continuous learning. Moreover, their deep sense of commitment and passion underscores the need for greater recognition and appreciation of the role of citizen scientists in bridging the gap between science and society. The findings presented in this paper shed light on the multi-faceted nature of science communication roles around the world, and the diverse avenues through which citizen scientists engage with public audiences. Their commitments extend beyond a singular role, manifesting in various facets of science communication, thus enhancing the current understanding of the dynamism in this field. The findings also underscore the importance of recognising and harnessing the potential of these individuals. As the correlations demonstrate, the people who are both citizen scientists and science communicators often identify as volunteers and/or educators. These individuals help bridge citizen science and science communication and, in doing so, contribute to closing the gap between scientific research and public audiences. These citizen scientists are navigating multiple roles and challenges. Their passion for science, commitment to their communities, and sense of responsibility drive them to disseminate complex scientific knowledge in an accessible and engaging manner. Despite the challenges they face, their work is underpinned by the view that fostering public engagement with science is paramount.

## Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving humans were approved by the Trinity College Dublin Research Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

## Author contributions

JR: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing–original draft, Writing–review and editing. EJ: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing–original draft, Writing–review and editing. AJ: Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing–original draft, Writing–review and editing. LB: Writing–original draft, Writing–review and editing. MH: Writing–original draft, Writing–review and editing. AT: Project administration, Writing–original draft, Writing–review and editing. CB: Project administration, Resources, Writing–review and editing. JC: Project administration, Writing–review and editing. SC: Project administration, Resources, Writing–review and editing. KD: Project administration, Writing–review and editing. JK: Project administration, Writing–review and editing. LM: Project administration, Writing–review and editing. JP: Project administration, Writing–review and editing. PR: Project administration, Writing–review and editing. FS: Project administration, Writing–review and editing.

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## Conflict of interest

Authors CB and SC were employed by the Company Ecsite. Author JK was employed by the Company Springer Nature. Author LM was employed by the Company SciDev Net. Author JP was employed by the Company Wiley.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The authors declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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# Forming bonds between molecules and communities through Project M

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Calcium carbonate is a compound that is well-recognized and very prevalent in daily life e.g., chalk, mussel shells and limescale. However, scientists still have many questions about its formation mechanisms, the different crystal forms it takes, and how we can control and direct this formation to produce this material with different properties. Project M was a chemistry citizen science project for UK secondary schools exploring the synthesis of samples of calcium carbonate under different reaction conditions and analyzing them at Beamline I11, an X-ray diffraction laboratory at the Diamond Light Source synchrotron. Science communication played a crucial role in the success of the project, connecting different communities to the science and creating unique opportunities to center and empower the Project M Scientists.

KEYWORDS
**chemistry, citizen science, science communication, calcium carbonate, youth**

## Introduction

Citizen science in the classroom creates practical opportunities to engage the youth in scientific enquiry (Makuch and Aczel, 2018), to improve their scientific literacy and science capital (Bonn et al., 2018) and to give them agency in their education (Ballard et al., 2017). Examples specifically for chemistry citizen science in the secondary/high school domain include monitoring the physiochemical parameters of coastal water quality (Araújo et al., 2022b), evaluating global medicine quality (Bliese et al., 2020), recording radon tests in their homes (Tsapalov et al., 2020), and comparing the bacteria resistant performance of non-fouling polymer hydrogels (Hansen et al., 2022). Teachers have also perceived added value for their own chemistry teaching practices through the use of citizen science (Araújo et al., 2022a). However, meaningful science communication with youth (and adults) is so much more than the act of providing or creating an opportunity for engagement in/with science (Petrie et al., 2006; Archer et al., 2015; Dawson, 2017; Murray et al., 2022b).

Citizen science has a plurality of definitions (Haklay et al., 2021) but within this work, we use the following definition: "*the active participation of non-professional scientists in the generation of new scientific knowledge*" (Perez et al., 2023). Our focus on citizen science in the classroom puts Project M in a context that is studied by at least three research traditions under their lead concepts of participatory research, science communication, and science education. Through participating in citizen science activities, students work not only on fake exercises but on actual and current research questions. Their participation, framed by the power and control they have in this endeavor, thus constitutes an involvement in science or participatory research (Cornwall and Jewkes, 1995). At the same time, this involvement in science is mediated through activities and communicative formats that address a particular public of science (usually non-professional scientists). In this way, citizen science in the classroom can be seen as a science communication activity (Horst et al., 2016). To express this connection, Metcalfe et al. have proposed to understand citizen science as participatory science communication (Metcalfe et al., 2022). Finally, citizen science in the classroom is not limited to just scientific and communicative purposes but can also have a particular educational function. In this way, such activities can be regarded as science education (Lewenstein, 2015).

Science education is typically distinguished into formal, non-formal and informal learning opportunities. Formal STEM learning is generally considered as happening in the classroom during routine class times based on educational curricula and studied under the concept of science education (Lewenstein, 2015). Non-formal learning is defined by UNESCO as "*organized and sustained educational activities that do not correspond exactly to the definition of formal education [and] may or may not confer certification*" (UNESCO, 1997). Informal STEM learning is a much wider domain that covers all other educational opportunities, for instance in the park, at a museum or at home (Morris et al., 2019). Due to the diversity of formats, functions and aims of non-formal and informal STEM learning opportunities, the latter can be described with the concept of science communication, which Horst et al. define as "*organized, explicit, and intended actions that aim to communicate scientific knowledge, methodology, processes, or practices in settings where non-scientists are a recognized part of the audience*" (Horst et al., 2016). Although science communication extends well beyond educational activities - it also covers mass-media communication of science and science fiction for example – capturing non-formal and informal STEM learning in this way has the advantage of defining it according to its function (communicating science), and not according to what it is not (formal education).

By considering citizen science in the classroom as participatory science communication in non-formal learning settings, we gain an important framing for the study presented in this paper. First, Metcalfe's emphasis that participatory science communication should incorporate different forms of knowledge and experiences (2022) creates space for students to practically implement their own conceptualizations in a real-life situation. This sensitizes our analytical view for how they can individually or collectively apply the theory from their textbooks to a meaningful scientific question, but also how they might communicate it. In turn, Bucchi (2008) highlights that science communication is a responsive process, rather than a tool for a prescribed form of event. Therefore, the students' success and the success of the citizen science project fundamentally relies on multiple layers of effective science communication between all of the relevant stakeholders. Here we describe how science communication bridged this gap between different communities to connect them to a real chemistry research question through Project M. We particularly highlight how co-creation and communication with our citizen scientists and our community were fundamental to the overall success of the project and share learnings from our experience.

## Context

Project M was a citizen science secondary school project in 2017 investigating the structure of calcium carbonate. Calcium carbonate has three main forms or "polymorphs": vaterite, calcite, and aragonite, which have the same chemical composition but a different crystal structure (arrangement of atoms) (Deer et al., 1967). Directing polymorph formation is important for being able to control material properties and is often done through the use of additives. Nature is already an expert in exerting this control, using proteins and organic molecules (acting as additives) to form the different polymorphs of calcium carbonate that make up for example the shells of sea creatures such as mussels and oysters (Lowenstam and Weiner, 1989; Mann, 2001). This so called biomineralized calcium carbonate has many favorable properties such as greater toughness and fracture resistance, created in part by the role of the additives in controlling polymorph and crystal structure. Inspired by this approach there has been much research using amino acids (that make up protein chains) as additives in calcium carbonation formation (Pokroy et al., 2006; Gilow et al., 2011; Kim et al., 2011; Borukhin et al., 2012; Green et al., 2016). Project M expanded on this work by synthesizing and analyzing a large number of powdered samples with different amino acid additives and concentrations, to reveal the effect of the additive on the polymorph and crystal structure.

Diamond Light Source is a synchrotron, a type of particle accelerator, that accelerates electrons to produce intense beams of X-rays. It has an experimental laboratory called I11 that uses these X-rays to perform diffraction experiments on powdered samples and analysis of the patterns that are produced provides information on the 3D arrangement of atoms in the sample. This technique gives valuable insights in the structural composition of the powdered samples. I11 can carry out very fast diffraction experiments on powdered samples – <10 s per sample (Thompson et al., 2009, 2011). This technique provides valuable insights in the structural composition of the powdered samples. Automation of these experiments has been made possible through a robot, which minimizes the time lost in changing samples manually (Thompson et al., 2011) and allow automation of the experiment data collections. By using variables like additive concentration in the calcium carbonate synthesis at various specified concentrations, 1,100 samples were planned. The combination of the robot and the fast diffraction experiments at I11 meant all of the Project M samples could be collected in a 24-h experiment.

## Project setting

### Audience, materials, and methods

Students (13–18 years old), teachers, teaching assistants and laboratory technicians were our target audience. We refer to them as the "Project M Scientists" to intentionally convey their meaningful contribution and define them with power in their role. This directly builds on from important conversations in the citizen science field (Shirk et al., 2012; Gadermaier et al., 2018). The Project M Scientists made powdered samples of calcium carbonate using different types and/or concentrations of additives to influence which polymorph formed. The protocol to make the samples was first sketched out in consultation with teachers, with a focus on trying to use resources and equipment available in schools and to convey key information on the science behind our experiment. The results from Project M were intended to be scientifically relevant to the research in the field so this also guided some of the experimental design. It was split into two stages to cover the making the samples ("sample synthesis") and the loading of the samples into small capillaries ready for analysis ("sample preparation"). This protocol was updated following frequent conversations and *in situ* tests with the Project M Scientists, ensuring each of the two stages for the experiment fit within a typical lesson timeframe (45 min) and complied with the relevant risk assessments. The final protocol was also converted into a video to provide a visual point of reference. In parallel with this, software for the Project M Scientists to access the data was developed. Once the optimal protocol was established and the feasibility was proven by tests with some of the Project M Scientists, the project was promoted via press releases and support from various networks and school mailing lists to identify secondary schools interested in participating. The time required to carry out the experiment and the fact the necessary resources would be provided were clearly communicated during this promotion. One hundred and ten schools were selected through the application process, located across the UK and with a focus on ensuring schools from underserved areas were represented. Each school was sent a box of resources, equipment, and chemicals (see Table 1), with the only variables per box being a chemical as the additive and unique sample codes for identification. Each set of experiments for the individual additive was repeated 4 times by different schools.

## Communication

The social media platform Twitter provided an important communication avenue for mutual exchange as well as for broader engagement with interested parties within and outside the project. It is widely used to share scientific results and insights including through humor (Su et al., 2022), and indeed creates opportunities for secondary science communication, whereby audiences share the messages within their own online communities (Hu et al., 2022). Schools were encouraged to share their experiences online via Twitter. This approach meant that the schools could individually assess the situation to ensure their own compliance with the relevant General Data Protection Regulation (GDPR) (European Union, 2016). We shared the project stages online using the @DLSProjectM account via tweets, photos (including re-tweeting those of the Project M Scientists) and short videos and we also used @DLSProjectMLive (an automated account) during the 24-hour experiment to share live results via the Twitter API. In total we had 66,000 impressions on this account between January and April 2017 in the run up to the experiment, with most of these impressions (27,900) occurring in April before and during the experiment. We also used @DLSProjectMLive during the 24-h experiment to share results live on Twitter. The Project M website was used to share the science and to provide resources for the schools (Project M, 2017). The website also included a blog written by Alice Richards, an undergraduate intern, to share the process of analyzing data. Many of these interactions created science communication opportunities with the schools as well as with external audiences (Figure 1).

## Access to data

Following the 24-h diffraction experiment, all schools were contacted to inform them that their data could be accessed. Access was a particularly tricky topic when working at a facility like Diamond Light Source: over 14,000 facility users create terabytes of data every year, so there are understandably strong security restrictions on who can access data and how. However, as a counterbalance, our Project M Scientists were now our users and had the right to see their data and the right to engage with it in a format that they could understand. A secure web interface was therefore created to enable the Project M Scientists to access their data, compare it with relevant data from other Project M Scientists and carry out analyses to identify what they had made. We also created a resource to provide details on the analysis and questions for discussion. To address security issues, sample codes and passwords were issued to each school, with a master code provided for teachers to give them an overview of their class's samples.

# Discussion

The communication flows within our citizen science project (presented in Figure 1) were shaped by multiple science communication opportunities. To structure our discussion, we are focusing on those opportunities centering around the audiences, the communities, co-creating the protocol, and the communications in and around Project M.

## Audience

A key question in science communication and citizen science fields is that of audiences and publics, with increasing reflection on the often-exclusionary nature of these practices (Pandya, 2012; Streicher et al., 2014; Dawson, 2018; Judd and McKinnon, 2021; Mahmoudi et al., 2022). We were particularly keen to reach Project M Scientists in underserved areas, so ensured this was a clear aim in selecting the schools through the use of established indices of deprivation (Ministry of Housing CLG, 2015). For the scale of our project, the obvious route was to promote via established routes that are already working, rather than expecting people to come to us (Humm and Schrögel, 2020). This meant tapping into pre-existing networks for Chemistry teachers via the Royal Society of Chemistry, Physics teachers via the Institute of Physics, teachers and students already interested in scientific research via the Institute of Research in Schools, Scottish Schools Education Research Center and schools already signed up to the Diamond Light Source Educational mailing list. We also sent out press releases to local and national press, as well as promoting it on Twitter and the Diamond Light Source website. However, we acknowledge the act of applying was by self-selection, so not all schools were able to do this. Future work may include working directly with underserved schools to support them with experiments like this and to facilitate wider participation from different communities.

## Building communities through science communication

An important consideration for citizen science projects is the fact that you might have to build a community of practitioners around a project from scratch. This heavily relies on science communication as a way of communicating to this community how their work contributes to and enables the implementation of citizen science, and why this matters (Halpern and O'Rourke, 2020). For us this included our own colleagues as we were working with a technical and communications team of more than 15 people who were mostly unfamiliar with citizen science or chemistry. It was therefore essential to bridge this gap to unite the team behind the same goals. We explored options to achieve this via science communication, such as presenting in internal site wide

TABLE 1 Project M box contents list.

| Item | Quantity | Item | Quantity |
|---|---|---|---|
| $CaCl_2.2H_2O$ | 2 x 25 g | Sheets of Blue Paper | 10 (1 per sample) |
| $Na_2CO_3$ | 1 x 50 g | Master sample sheet for teachers, with all barcodes, logins and additives concentrations for their calls | 3 copies |
| Additive | 1 | Student sample information sheet with the barcode, login and additive concentration for their sample | 3 copies for each of the 10 samples |
| Large funnels | 10 (1 per sample) | Teacher handouts with scientific background detailed instructions for setting up and running the experiment | 3 |
| Filter paper | 1 Packet | Student handout on the science behind project M | 30 |
| Kapton capillaries | 20 in a small bag (2 per sample) | Student instructions | 30 |
| Glue | 1 | Student worksheets | 30 |
| Vials + Lids | 10 | Materials safety data sheet | 1 |
| Electric toothbrush | 1 | Example risk assessment | 1 |
| Tweezers | 2 | Stamped addressed returns envelope | 1 |
| Small plastic bags | 10 (1 per sample) | USB sticks | 2 |
| Large plastic bags | 10 (1 per sample) | Diamond pens | 1 pack for the class |
| Unique Sample Barcode Labels for Small Plastic Bags | 10 (1 per sample) | Diamond literature | |

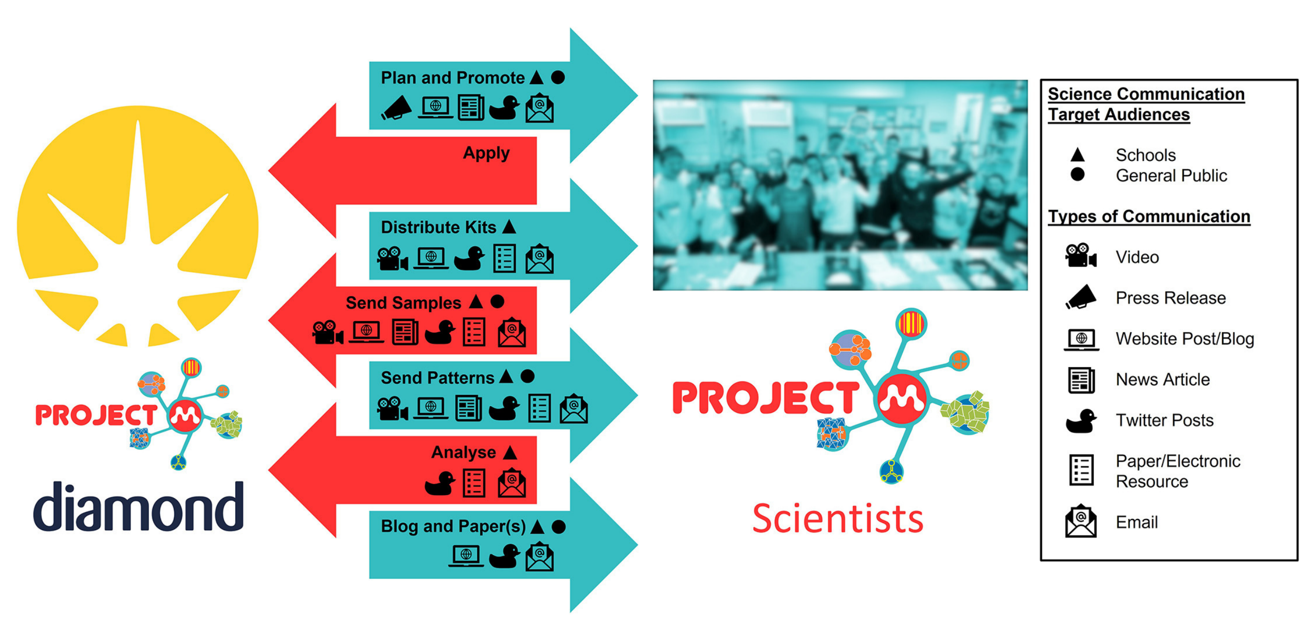


FIGURE 1
Opportunities for and types of science communication used throughout the different stages of Project M.

meetings, sharing the project aims at regular points as reminders in meetings and having local conversations. The latter proved to be particularly important, as it simultaneously enabled us to build relationships and empower our team to connect with the science of calcium carbonate. We also conveyed the role of each part of work to the overall product, which resulted in cross-fertilization of ideas to create the Twitter account @DLSProjectMLive. The additional bonus we noticed was that our team had a strong sense of ownership around their work in Project M, regularly asking follow-up questions on their own initiative about progress of both the project and the science and responding enthusiastically to requests for support.

This interest extended to the broader community of colleagues at Diamond Light Source, who were not directly involved in the project. We actively engaged in internal dissemination opportunities to reach them (such as the internal site wide meetings) and intentionally created opportunities for visibility and engagement with the science and the citizen science. A clear example of the latter was the 8-h box packing marathon that took place in the Diamond Atrium, where our colleagues were able to see the packs being assembled and chat with us as we worked. Many of these staff volunteered their time of their own accord to help prepare the boxes for the Project M Scientists, asked follow-up questions about progress throughout the project, and promoted the project to their local schools.

Lots of the Project M Scientists used Project M as an opportunity to build their own community and communicate science in school. Whether doing Project M as part of regular school classes or in after-school science clubs, informal feedback from teachers involved in Project M highlighted that students attributed value to their contribution, similar to the feedback from youth citizen scientists working with Ballard et al. (2017). We are aware of one example of two schools using Project M to build a community between younger and older students (in middle school and high school respectively). Older students gained valuable experience in mentoring and younger students had unique opportunities to share their ideas and discuss science outside of standard classroom structures. Teachers were very enthusiastic about participating, with many commenting on their excitement about the opportunity to do real chemical research with their students and some requesting citizen science chemistry projects just for teachers.

## Co-creating the protocol

The starting point for any protocol is understanding what it sets out to achieve and the context in which it is to be deployed. The framing of science communication as social conversation (Bucchi and Trench, 2021) provides an important reflection point here: in co-creating a citizen science project with schools, we need to open ourselves to the relationship with our citizen scientists. Fundamentally, this means we as citizen science practitioners should truly listen and acknowledge their perspectives before starting (Hecker, 2022). Institutional barriers or lack of materials/links to curricula are major barriers for teachers to engage their students in citizen science (Kloetzer et al., 2021). The context of structure within the ecosystem of co-creation was therefore very important for us in order to successfully achieve our aim to create a valid and robust scientific methodology for Project M (Kaletka et al., 2016; Eckhardt et al., 2021). We actively sought to include teaching staff early in the project development process to address this. They are experts in science education in their classrooms and in their curricula, so acknowledging this and the context of role here is very important.

In Project M, conversations with teaching staff directly impacted the protocol and the strategy, where they shared the need for connections to the curriculum and science education learning outcomes (Kelemen-Finan et al., 2018; Scheuch et al., 2018; Roche et al., 2020; Aristeidou et al., 2022). The division between science education and science communication in the classroom and in research can imply that they have little in common, when the reality is that they fundamentally share the common goals of education, entertainment and engagement in and about science (Baram-Tsabari and Osborne, 2015). The curriculum is therefore not intended to limit or restrict the potential areas of research that school citizen scientists can engage with. However, early conversations with teachers quickly identified synergies with the curriculum for Project M and they highlighted positively the opportunity to connect the practical skills and ideas delivered in class to a real-life situation. These conversations were very helpful for making these connections and for ensuring the gap between what is known and what is not known can be bridged within the time allocated.

For the project methodology, we started by seeking initial feedback on the average school laboratory resources through conversations with teaching staff from a local school. Using this information, we created the protocol, which was tested with a small group of local students and teaching staff (ca. 10 students and three teaching staff). We observed them doing this first pilot and had discussions afterwards to refine and improve the methods. The refined methodology was taken to a second school, who had not participated in any of the initial testing (and were therefore completely fresh to the project). Twenty students and three teaching staff participated in the second iteration and shared their input. We had follow-up conversations with teaching staff to assess the final protocol and addressed all feedback before finally scaling the project out to all schools. This iterative process was time-intensive, as with the challenge of resourcing most co-creation citizen science projects (Gunnell et al., 2021).

The co-design process was also used in the creation of instructions and handouts for all of the Project M Scientists. Language shapes the intent and purpose of an interaction and is frequently used as a way of asserting power. It can be completely impenetrable due to jargon (Bullock et al., 2019) or performative (Kueffer and Larson, 2014) when it is delivered in a corporate or academic way to people outside formal institutions. We wanted to make our resources accessible to students so they could use them with minimal support, but we also wanted to introduce them to new vocabulary. The co-design process meant we could identify problematic terms or phrasings and ensure we used terminology in use in the classroom – e.g., most UK secondary schools used deciliters (dL) as opposed to the research lab standard of milliliters


FIGURE 2
Tweets from various schools sharing their experiences loading capillaries.

(mL). In cases like this where we knew many laboratory technicians, teaching assistants and teachers would be preparing the materials for and sharing the protocol with their class, we wanted to minimize their burden. The protocol was therefore designed to be easy to follow, to provide learning opportunities, to share good practice (e.g., wearing safety spectacles) and to ensure it was reproducible and consistent for the scientific credibility of the results.

The contents of the supply box that was sent out to schools outlined in Table 1 were selected for a combination of scientific and practical considerations, most of which only became obvious after conversations with teaching staff to understand their local contexts and needs. As mentioned above, a central focus was to minimize work for the teaching staff, so multiple copies of instructions were printed with copies for students and more detailed copies for teaching staff to support them in preparing for the experiment. We also provided two back-up USB drives containing all documents and videos in case extra copies were required or in case internet access was not possible. Carrying out risk assessments is an essential part of laboratory chemistry, but it is not possible to write a universal risk assessment that would legally cover the schools. We therefore provided an example risk assessment to support school staff with this, but explicitly stated that each school needed to do their own. Scientific consistency in methodology is important in the context of building trust in citizen science data (Burgess et al., 2017), but discussion with teaching staff highlighted the different filter paper and filter funnel sizes available in school laboratories, as well as varying amounts. This would induce a serious variable in terms of filtering time across difference schools and would limit the number of samples that could be made simultaneously. We therefore provided the same size funnel and filter paper to ensure all samples could filter at same rate and so the 10 samples could be made within the same class period. Petri dishes were also provided as schools reported not having access to enough of these for the number of samples we planned – every sample needed to dry for 1 week in a petri dish.

We provided all chemicals apart from the solvents to ensure the same standard and quality, and this even included ensuring all samples were from the same batch. Sending solvents by post is not possible in the UK, due to the high risk of flammability. However, discussions with teaching staff revealed some variability in what was available to them, but acetone, for example, was a commonly available solvent. Some items in Table 1 were specifically included for the loading of the capillaries, which included the spatula to load the powder into the capillary, the tweezers, and the electric toothbrush to facilitate the packing of the powder, as well as the glue to seal the capillaries. From our visits to the two schools who piloted the protocol, we saw that many workbenches were light gray or white, which would not provide a strong enough color difference to see the white calcium carbonate powder. The sheets of blue paper were therefore included to provide contrast for the capillary loading. The final practical items were barcoded vials and lids for the remaining sample not used in the capillary loading, barcoded small bags to hold the capillaries, barcoded larger bags to hold the vial, and a stamped addressed envelope for returning the samples. The barcoding enabled us to track samples and identify them throughout the experiment.

Frequent reality checks are critical to ensure what you are proposing is possible for the target audience. There is often a gap between what people sign up for and what they think they are signing up for, as well as a gap between the expectation and reality of resource and time availability in schools (Aristeidou et al., 2022). This is particularly true when thinking about school laboratories/equipment or access to computers or printers. We intentionally built the project to be achievable within a secondary school chemistry laboratory – ensuring for example, that the weights we were requesting were within resolution of the weighing balances available (informal feedback from teaching staff highlighted that generally the minimum is 0.01 g) and using conical flasks rather than beakers as more schools use these. In the UK, many teachers have a limited printing budget and computers are a limited resource, so we printed out everything for the schools to ensure they did not have to use their own budget on our activity. These materials/resources often have lifetimes beyond the project, which teachers appreciate (Araújo et al., 2022a). We provided individual instructions and reporting sheets for each Project M Scientist (plus spares) to ensure everyone had their own copies enabling them to input their own results. This was also important in promoting good lab practice and consistency across the participating schools, as it ensured Project M Scientists could follow the same lab protocol independently.

## Communication resources to support learning

To support learning needs *in-situ* in the laboratory, we recorded three videos: (1) Introducing the science of calcium carbonate, the diffraction experiment, and Diamond Light Source, (2) the synthesis of the samples and (3) the loading process for the capillaries. For (2) and (3) we recorded videos of ourselves performing each stage of the experiment. These two videos were scripted to ensure our language matched the language of the protocol and to ensure our version of the protocol was exactly the one described in the materials we were sending to schools. These videos provided additional opportunities to share the science behind the project and to connect with our Project M Scientists. From looking at the samples, we have the impression that schools were more exposed to scientific practice and process. The capillary loading process is tricky (as communicated to us by the schools in tweets shown in Figure 2), and many experienced scientists find this quite difficult. It is also quite challenging to describe the steps in a written document, so the video was an opportunity to demonstrate best practice and techniques for doing this. The (often sticky) powder must be packed without gaps inside a 0.5 mm Kapton tube, which can be a delicate process. The consistency of the packing of the loaded capillaries across samples from a school was therefore an interesting insight into whether they had watched the video to pick up the skills involved.

Awareness of the variety of IT security protocols and software available in schools led us to develop a custom web interface to enable facile visualization and analysis of the data, circumventing requirements for specific software packages or requirements for software to be downloaded. However, access extends beyond the act of getting the data to also include the act of engaging with the data, which is where science communication comes into play. A resources pack was built to accompany the web interface to convey how to carry out analyses of the samples (Project M, 2017). This built on concepts that had been introduced in the initial pack and provided prompts for critical thinking around the scientific process (e.g., sources of errors) with links to real world problems.


FIGURE 3
A collage of tweets demonstrating the communication on Twitter from the Project M Scientists and the @DLSProjectM account.

The intellectual tools developed through critical thinking provide important foundations in problem solving, decision making and in interacting with others (Vieira et al., 2011). These prompts therefore provided opportunities for the Project M Scientists to gain an understanding of the chemical composition of their individual samples but also to reflect on and rationalize how real-life experiments work.

## Communicating Project M

The act (and art) of communicating about science usually involves multiple modalities. In our case, we had multiple communities involved including the Project M scientists, chemists and synchrotron users and our own colleagues. This translates to varying information and engagement needs for this broad community of people doing and interested in the science. The authors and the communications team at Diamond Light Source communicated the science of Project M via big press releases to national media (Diamond Light Source, 2016, 2017), interviews with TV and radio stations, conference talks, social media and more, as detailed in Figure 1. These experiences combined with the creation of the videos for the Project M Scientists enabled the team to develop skills and confidence in media work and in communicating science to different audiences via different forms of media, e.g., the key talking points with a science journalist for print media need to be delivered differently to a live radio interview on a local morning show. The Project M blog was also a useful way of demystifying the scientific process and sharing initial results (Project M, 2017), and some updates were shared with schools via emails. Simultaneously, our Project M Scientists were also busy doing their own science communication: tweeting their experiences, writing articles for school newspapers, presenting at school assemblies, and doing interviews with local press (Figure 3) (Campbell, 2017; UnknownReporter, 2017). In learning about this, additional resources should be planned for and shared with citizen scientists to ensure they have a variety of options for how to share their experiences and the project outcomes.

The use of only one social media platform prevented us from engaging with a wide variety of people, with clear limitations to the potential audience on Twitter (Robson et al., 2013; Tancoigne, 2019). We know that many of our younger Project M Scientists were not able to engage with us or indeed do not use Twitter. Even considering the engagement we had, algorithms limit who engages or even sees your tweets. However, interacting with youth within the important legal framework of GDPR has its own challenges across all social media. By sharing the account @DLSProjectM and the hashtag #DLSProjectM with the schools, they had the power to assess their own compliance with GDPR. We still received quite a few interactions from schools, with many sharing feedback or photos and one school even video streamed their experiment live via the Periscope service (see Figure 3). One school also shared how their students would use Project M to work toward their bronze CREST award, which is an optional STEM accreditation that UK students can work toward (also Figure 3).

A surprising audience that we were not expecting to draw in via Twitter was the scientific research community who were not involved in Project M. Citizen science is not super common in chemistry (Motion, 2019), crystallography or in synchrotron science. A recent survey of European Citizen Science projects highlighted that only 0.6% of projects count as "chemistry" (Hecker et al., 2018). This meant that many of our scientific colleagues within and beyond Diamond Light Source were curious about what was going on. An important point to note here is that this meant our Twitter accounts @DLSProjectM and @DLSProjectMLive were simultaneously communicating science to two very different key groups: the Project M Scientists (mainly teaching staff who were running school or department accounts) and the scientific research community. This required science communication about the science and science communication about citizen science, with both groups being interested in one or both, whilst also ensuring we centered the Project M scientists and their work. Sharing live results and the scientific process online was therefore one small way of building different dimensions of trust (Brondi et al., 2021) in Project M and citizen science.

## Challenges

An important reflection on the protocol is to consider the completion rate. A total of 80% schools returned samples, although not all are a complete set (Figure 4). We believe this is a good completion rate given the high workload involved in making and preparing the samples. Some issues reported by teaching staff via email were curriculum pressures and staffing problems, which in turn meant reduced time for the experiment or that only a few samples could be made. Variations in class timing or in science club timing and the fact two sessions were required may also have affected the completion rate. Whilst budgetary restraints and having enough samples for statistical significance are important considerations, options such as designing a shorter experiment, reducing the number of samples per class, or providing more detail on what would be involved so they can think about logistics when signing up could be explored to address this as there is clearly interest in this type of project. Some of the issues were also due to our own inexperience at running projects at this scale or to experimental challenges. However, the latter unexpectedly provided an important reflection point: a teacher shared positive feedback on the power of citizen science to demonstrate to their students that real science doesn't always work. Negative results and/or failures are not well communicated in formal academic journals, let alone in science communication, but this is an important and welcome way of humanizing science that should not be underestimated (Zaringhalam, 2016; Murray et al., 2022a). Another consideration in retrospect is that although many teaching staff were busy, there was a lot of enthusiasm and good will from them. There would have also been an interesting opportunity to build a community for the teachers involved in Project M, such as through collective conversations, an online forum or targeted further dissemination, which is an important factor for future work.

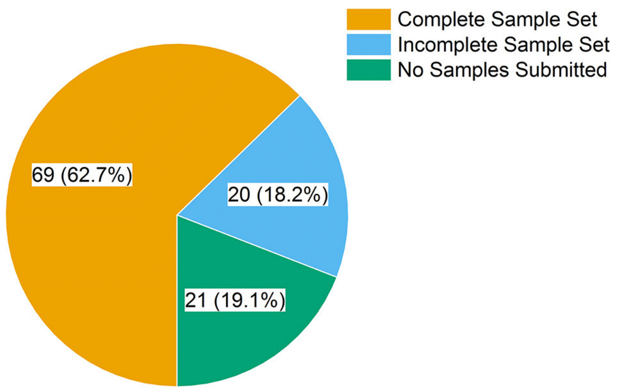


FIGURE 4
The completion rates for the submission of samples sets for Project M, where each school applied to carry out experiments for one full sample set. The number of sample sets is therefore directly equal to the number of schools.

## Conclusion

Chemistry citizen science projects in the classroom create unique opportunities for research, for youth agency and skill building in their education, for professional development for teachers, teaching assistants and lab technicians, in addition to building communities at different scales. In the case of Project M, the community of people involved started as a small team within Diamond Light Source, but quickly grew to include the Project M Scientists, other colleagues at Diamond, various stakeholders, and the broader science community. The science communication methods we deployed at different layers were fundamental to the establishment and growth of the communities. This required careful consideration and challenging of assumptions about factors like language, facilities, equipment, access, time, and resources, which all directly affected the success of the project. Ignoring these factors or assuming what was possible would have disempowered the Project M Scientists by creating more work for them to participate equitably. Science communication was therefore crucial to bridge the theoretical expectations and the practical reality of citizen science for Project M and enabled opportunities for the Project M Scientists to engage and participate in real research in a meaningful way.

## Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

## Ethics statement

Teachers who signed up on behalf of their school to participate were informed of the aims of the research, including its publication goals, prior to consenting to take part. Separate consent beyond the consent obtained during the sign-up process was not necessary. Further ethical review and approval was not required for this study in accordance with the local legislation and institutional requirements.

## Author contributions

CM and JP conceptualized the paper, wrote, and reviewed the article. LH and RO'B contributed to the implementation and reviewed the paper. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

RO'B was employed by the Wellcome Trust.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The handling editor YG declared a past collaboration with the author CM.

## Publisher's note

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# Communication strategies in an international school citizen science program investigating marine litter

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Communication is an essential element of science, and while it is important in all scientific endeavors, it gains substantial strategic relevance in citizen science projects. For a school citizen science program to be successful, an adequate communication strategy needs to achieve a balance between learning objectives and the generation of scientific knowledge. In this community case study, we report on the communication strategies of an international network, namely, the citizen science program *Científicos de la Basura* (*Litter Scientists*), which collaborates with schoolteachers and schoolchildren to investigate anthropogenic litter on marine beaches and in rivers. The program has been active in Chile since 2007, and as of 2018, it had expanded to the 11 countries from the central and southern East Pacific. More than 40 teachers and collaborators from these countries work in this network making an effort to connect the research activities with the learning objectives of the school curriculum. The communication between the coordination team and the teachers includes three main elements (1 - design and planning; 2 - training and research; 3 - evaluation and sharing), with the following activities: (1a) regular internal communication within the coordination team to design, motivate and supervise adequate research projects, (1b) communication with teachers to design appropriate learning materials (co-creation) and get their feedback on the planned research activities, (2a) sharing the final research plan and transfer methodological skills through regular training of the teachers, (2b) responding to methodological questions by the teachers about the sampling, and coordinate data collection and validation, (3a) guiding teachers and schoolchildren in the evaluation and interpretation of their research results, and (3b) encouraging teachers and schoolchildren to communicate their scientific findings to the wider community. Intense internal communication and regular exchange with teachers guarantees successful learning and rigorous scientific information. The main challenges for the program are team capacity, socio-economic stability, internet access, and teachers' workloads. Recommendations to achieve successful communication and good science are efficient team communication skills, customized contacts, collaborative work, guidance of field work, feedback from participants, and promoting the sense of community.

KEYWORDS

volunteer participation, schoolchildren, school teachers, learning objectives, education goals, customized communication, research activities, plastic pollution

## Introduction

Engaging members of the public in scientific research can have important learning benefits for the participating "citizen scientists" in addition to producing powerful scientific information (Bonney et al., 2009) (note: here we use the term "citizen scientist" to refer to people partaking in research processes, usually without a formal scientific education, even though this term is debated, see, e.g., Eitzel et al., 2017; Heigl et al., 2019). Because citizen science projects typically involve diverse participants from different backgrounds, good communication is especially important (Anderson et al., 2020). Communication for citizen science projects/programs often goes beyond conventional science communication that simply aims to inform the public about research findings in writing or in participatory discussions and presentations (Wagenknecht et al., 2021). Communication in citizen science serves to (i) develop research questions, (ii) design and test methodological approaches, (iii) collect data and samples, (iv) gather and validate the data, (v) analyze data and interpret the results, and ultimately (vi) share the new scientific findings. In particular the internal communication takes different angles (goals) and perspectives (project participants) in citizen science as its desired outcome is project-specific (Rüfenacht et al., 2021; Hecker and Taddicken, 2022).

Many authors emphasize the importance of effective communication with citizen scientists and also with the general public (e.g., Bonney et al., 2009; de Vries et al., 2019; Roche et al., 2020; Dittmann et al., 2023). These communications are essential and usually happen between a team of program professionals coordinating the research projects and the citizen scientists as participants in the investigation. The internal communications among the members of the program teams, usually a team of scientists and citizen science coordinators, are also critical for the success of citizen science projects, yet they are often overlooked when describing the interaction space of these projects. Scientists and project coordinators should reflect regularly about their roles and goals in order to achieve successful citizen science projects (Hecker and Taddicken, 2022).

The dialogue between scientists and participants is especially important in school citizen science projects, because teachers are interested in effective learning outcomes for their schoolchildren whereas scientists place emphasis on data/samples for their scientific research (Zoellick et al., 2012; Atias et al., 2023a). The challenge for school citizen science programs is thus to achieve synergies between the educational goals and the advancement of scientific knowledge (Roche et al., 2020), which requires extensive communication and time (Benichou et al., 2023). In this contribution we share our experiences regarding internal and external communication strategies of the school citizen science program *Científicos de la Basura* (*Litter Scientists*). Members of this program have been investigating marine litter pollution in Chile and Latin America since 2008 (Bravo et al., 2009), making efforts to achieve a sustainable balance between educational and scientific outcomes.

## *Científicos de la Basura* network

The citizen science program *Científicos de la Basura* (*Litter Scientists*) develops annual research projects where scientists collaborate with schoolteachers and schoolchildren (ages 10–18) in the study of anthropogenic litter. The program pursues four main goals: (i) contribute to the scientific education of schoolchildren, (ii) foster environmental awareness among the schoolchildren and local communities, (iii) generate relevant information about anthropogenic litter, and (iv) support decision-makers with useful data (all materials including learning and research guides, outreach reports, and scientific publications are available on the project website: www.cientificosdelabasura.cl).

From 2008 to the present, the program conducted national research projects about microplastics and macrolitter on sandy beaches (Hidalgo-Ruz and Thiel, 2013; Hidalgo-Ruz et al., 2018), litter in the rivers of Chile (Rech et al., 2015; Honorato-Zimmer et al., 2021), and it also surveyed the knowledge, perception and attitude of coastal inhabitants about marine litter (Eastman et al., 2013). In 2016, the program did a first binational project comparing macrolitter on beaches from Chile and Germany (Honorato-Zimmer et al., 2019) and in the following years also contributed to the establishment of the *Plastic Pirates* program in Germany (Kiessling et al., 2019; Dittmann et al., 2023). Both programs work independently, but given the similarity in research protocols they occasionally collaborate, e.g., in exploring how participation in a citizen science project influenced knowledge and attitude of the schoolchildren (Kruse et al., 2020; Wichmann et al., 2022). In 2018, the *Científicos de la Basura* program created the Latin-American Network, integrating the 11 countries between Mexico and Chile that share the Pacific coast.

The program team consists of scientists with extensive expertise in marine litter research and of citizen science coordinators who have worked with teachers and scientific outreach activities for many years (Figure 1). However, these roles are not always strictly separated, as scientists are also involved in coordination, and the coordinators also curate data and contribute to the analysis and interpretation of the results. The coordinators fulfil similar roles as the citizen science enablers in the model suggested by Salmon et al. (2021). In addition, a teacher who has been teaching at a local school for >15 years, and who has participated with his schoolchildren since 2008 was fully integrated in the program team starting in 2018 (J.M. Sepulveda, co-author of this publication).

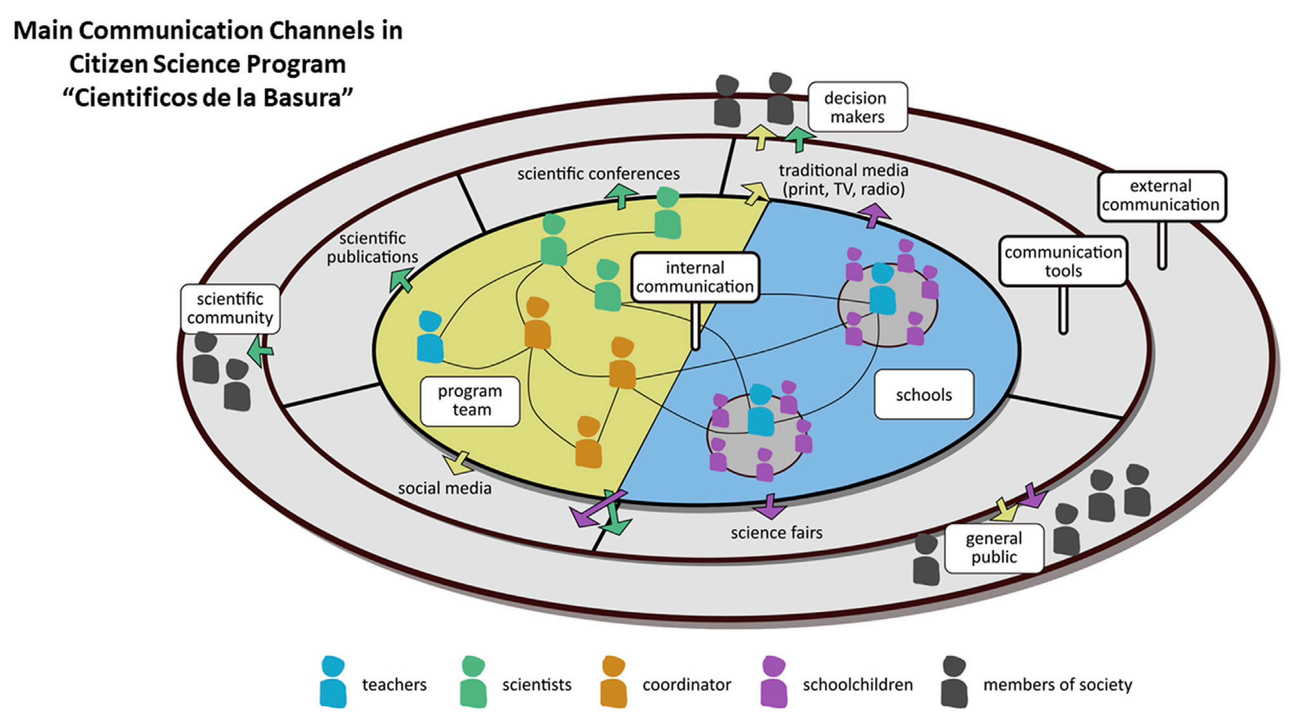


FIGURE 1
Organisational structure of the Latin-American Network of the citizen science program *Científicos de la Basura* with the program team (bright-yellow) and the school network (blue). Scientists marked with green, citizen science coordinators with ocher-yellow, educators (teachers) with blue, and schoolchildren with purple.

In order to reach the previously described program goals (learning, awareness, information, decision support), a key step has been to build a committed and trained teacher community. The individual research projects are primarily of the contributory citizen science type (Senabre Hidalgo et al., 2021), but the network offers a variety of activities to be involved in many more scientific processes, such as the design of educational materials and sampling guides and the dissemination of scientific results in science fairs, among others. Likewise, the program team is regularly evaluating and considering both the motivation of the participants (teachers and schoolchildren) and feedback regarding the program's scientific and education goals. In this contribution we share our experiences, highlighting which communication approaches were successful for being able to run a citizen science project initiative for 15 years and involving >12,000 schoolchildren and their teachers in research projects on anthropogenic litter. In this paper we focus on the first 2 years of the Latin-American Network (2018-2019), but we also mention briefly how the program adjusted in 2020 to the challenges of the COVID-19 pandemic. We further critically discuss aspects where we (and coordinators of other citizen science projects) could improve in the future.

## The Latin-American Network and its research projects

Starting in 2018, the Latin-American Network has been initiated by the *Científicos de la Basura* program, and it is being maintained and coordinated by the program members since then. During the first semester of 2018, teachers and schools from the East Pacific coast were contacted and invited to participate in citizen science activities related to anthropogenic litter pollution (Figure 2). While the invitation was open to all schools along the Pacific coast of Latin America, we aimed at geographic representation, and therefore we often contacted collaborators and teachers from particular countries and coastal localities. In response to our public and personalized calls, 33 schools initially committed to participate in the Latin-American Network by signing a formal agreement letter (signed by the school director and the teacher). All activities were accompanied by the corresponding consent forms and the overall project was approved by the Scientific Ethics Committee of Universidad Católica del Norte (resolution F.M. N°10, 11 September 2018).

For each annual research project, the program team prepared four to five learning/training guides, two research guides, and two evaluation/outreach guides to walk the participants through how to analyse and share research results (Figure 2). These guides were in PDF format so that they could be easily printed by the teachers, and they were supplemented by short instructional videos. All of these materials and further support from the coordination team were free of charge for the teachers. During the project period, the school teachers were encouraged to implement all guides in the classroom and engage the schoolchildren in a variety of scientific processes. Although not all teachers had sufficient time to do all the activities (the end of the school year often approached before completing the evaluation/outreach guides), all participating schools at least conducted the research activities.

Teachers could apply for a basic research stipend/grant (up to about US$250), which they could use to pay for transport, food,

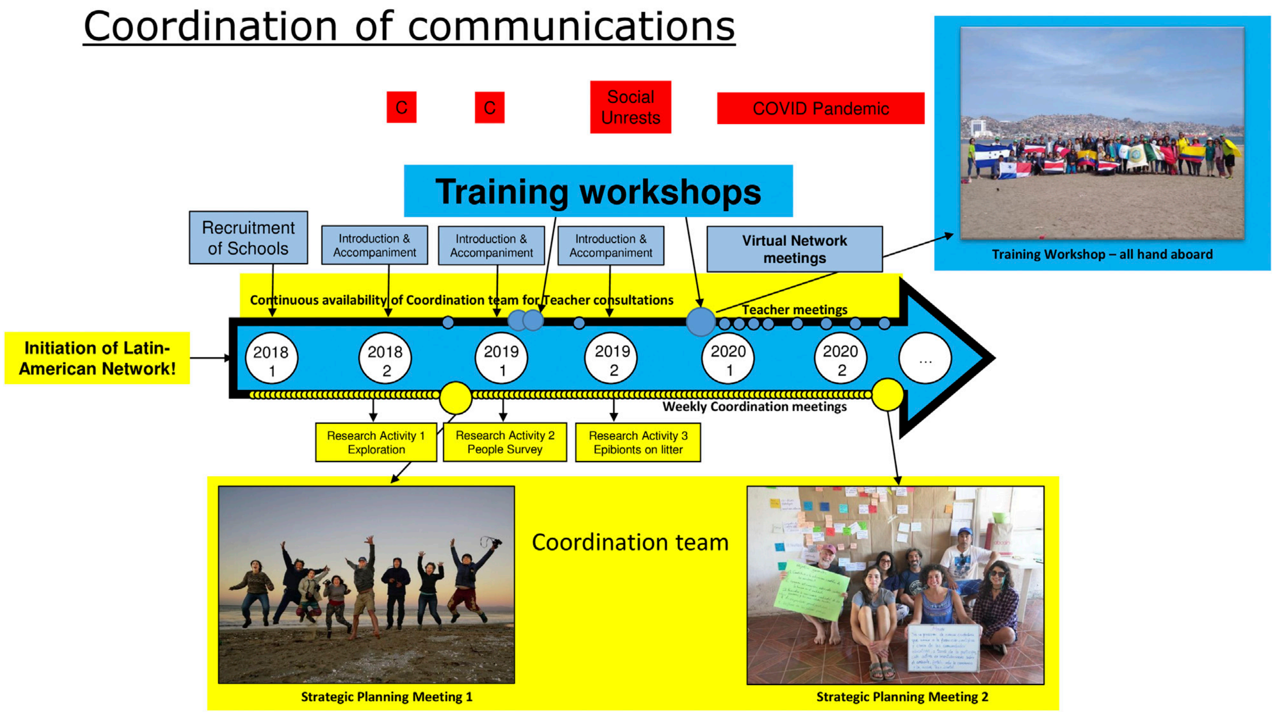


FIGURE 2
Project time line with major elements and events. Main project (large blue arrow) and complementary project (training workshops) are shown. On the lower edge of the main project arrow the internal communication of the program team is highlighted by strategic planning meetings (large yellow dots) and weekly design and organisational meetings (small yellow dots). On the upper edge of the main project arrow the teacher training workshops (large blue dots), and the regular network meetings (small blue dots) are shown. External factors affecting the network activities and communicational strategies are climatic events (C = hurricanes, rainstorms, floods), social unrest in Chile (October—December 2019), and the global COVID pandemic, shown in the upper part of the figure with red boxes. Working guides can be found at www.cientificosdelabasura.cl.

basic research materials (gloves, bags, *etc.*), or other needs such as photocopies. The program team also produced an environmental storybook (see https://zenodo.org/record/7081049), which was printed and then shipped to the teachers so that each participating child would receive a personal copy. The story is related to marine litter and its impact on sea turtles and served to increase schoolchildren's environmental awareness and to motivate them to participate in the citizen science activities.

In 2018/19, three research projects were conducted. Starting in August 2018, the participating schoolchildren explored their surroundings and shared general impressions of their schools, their locality and their beaches with the schoolchildren from the other countries through various formats, including hand-drawn pictures (working guides available at https://doi.org/10.5281/zenodo.5317138); exchange of pictures was mediated by the coordinating team via the project website. While the schoolchildren knew that they were participating in a research network about marine litter, these exploration activities did not specifically ask them to record litter. Interestingly, almost none of the hand-drawn maps from their daily path to school contained any litter, while many drawings from their local beaches did feature litter items (De Veer et al., 2022). In the first semester of 2019, schoolchildren visited public places and interviewed members of the general public to investigate the knowledge, perception, and attitude of the coastal population about marine litter (working guides available at https://doi.org/10.5281/zenodo.8396878). In the second semester 2019, the schoolchildren collected litter items on their local beaches and inspected these for epibionts, i.e., marine organisms that colonized floating litter items during their journey with the ocean currents (working guides available at https://doi.org/10.5281/zenodo.5906766). Throughout the duration of these research projects, the program team regularly contacted all the network teachers, was readily available for consultation, and accompanied them in the learning and research activities (Figure 2).

## Communication strategy of the *Científicos de la Basura* program

### 1) Design and planning of research activities

#### 1a) Internal Communication

The program team (four to eight people) met on a weekly basis to discuss all aspects related to the functioning of the program, including scientific questions, coordination, financial administration, data management, evaluation of results, and outreach activities. A main part of these discussions was dedicated to designing and planning of the research activities. Additionally, two strategic 3-day planning meetings were held during the period 2018–2020 (Figure 2). The first task of the project planning was identifying a clear scientific question and defining the minimum data requirements needed to respond this question. The design of the adequate research activities with detailed instructions for the participants (teachers and

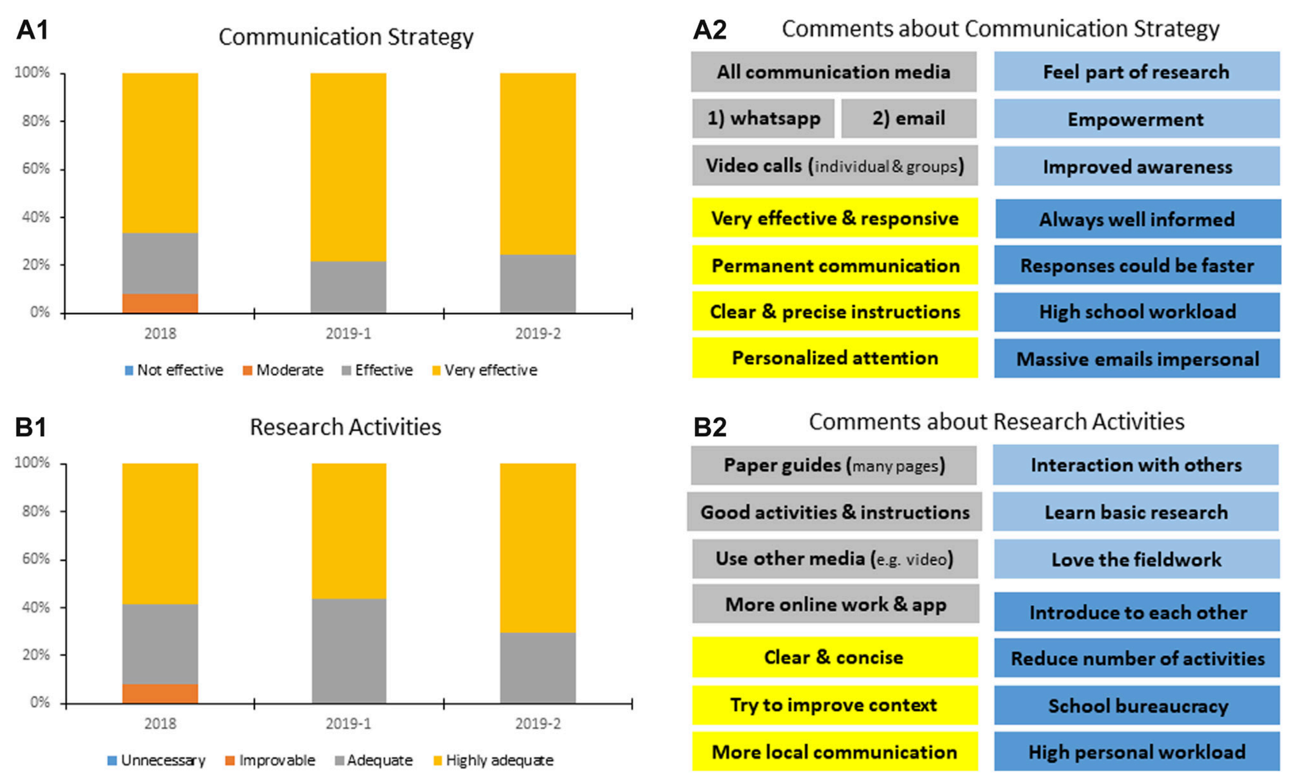


FIGURE 3
Percentage of teachers responding during the three research projects (one project each semester) to the questions **(A1)** "Do you think that the communication strategy that the program team has had with you has been effective?", and **(B1)**" Do you think that the activities suggested in the work guides are suitable to determine the local and environmental reality of your students, and in turn to learn about the realities of other countries?". Boxes on the right side **(A2, B2)** show for each of these two questions the main comments by the teachers referring to the communication tools (gray), role of the citizen science coordinator (yellow), schoolchildren (light blue), and teachers (blue). Number of teachers responding after each project were 24 (2018), 23 (2019-1), and 37 (2019-2).

schoolchildren) typically extended over several months and often required additional meetings of a smaller subgroup that internally agreed to be responsible for the respective scientific projects. During the design phase, the evolving research guides were regularly revised by all members of the program team. The results of the first field tests done by volunteers (e.g., one teacher with her/his course) were also evaluated by the entire program team, and problems with the research activities were identified and resolved. The continuous dialogue within the program team, consisting of the citizen science coordinators, the scientists, and the teacher (Figure 1), ensured feasibility and rigor of the final research activities, which are simple and straightforward as desirable for citizen science activities (e.g., Le Coz et al., 2016). While these discussions were sometimes intense and time-consuming, the resulting research guides have been applied widely, and they have generated essential baseline data about anthropogenic litter in Chile (Eastman et al., 2013; Hidalgo-Ruz and Thiel, 2013; Rech et al., 2015; Hidalgo-Ruz et al., 2018; Honorato-Zimmer et al., 2021) and in other countries (Kiessling et al., 2019; Gaibor et al., 2020; Garcés-Ordóñez et al., 2020).

### 1b) Teacher feedback

During the planning of each research project (see *1a Internal communication*), the citizen science coordinators consulted the teachers about their interest in participating and resources of their school, the local coastline, or litter items (e.g., presence of epibionts on litter items). This information gathered during these conversations was then taken into account during the project design. Once the research activities were taking shape, the teacher from our program team carefully revised the research guides and provided pedagogic feedback.

At the end of each research project (after each semester), we obtained both praise and constructive feedback from the teachers through questionnaires and personal conversations about the communication during the project development, the activity guides, and many other aspects (Figure 3). The suggestions were carefully evaluated and implemented in the new research projects whenever possible, leading to slight increases in the teachers' satisfaction with the program and the materials over time (for selected examples see Figures 3A, B). Many of the initial teachers continue to work with us to the current day.

## 2) Training and research activities

### 2a) Training of teachers before the research

Besides sharing the working guides and research materials with the teachers, we also conducted virtual trainings in form of multi-participant videocalls where background about the research motive was given and the rationale underlying the research question was explained. Due to the different time zones and personal schedules,

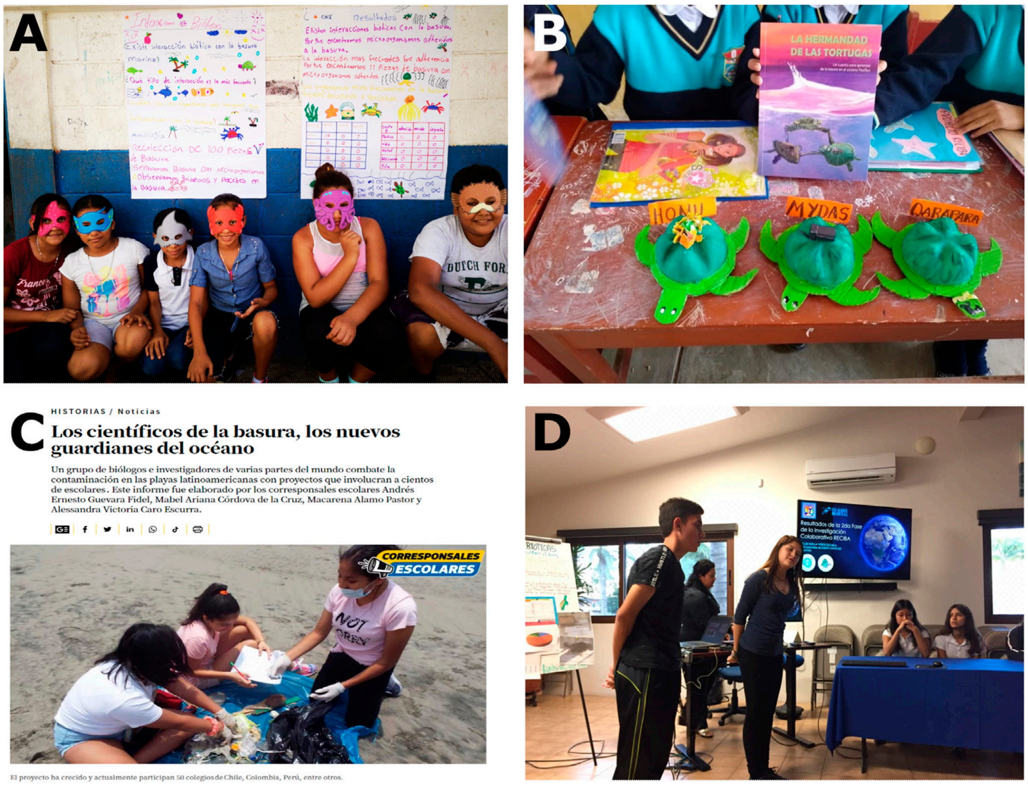


FIGURE 4
Examples of communication activities carried out by the schoolchildren participating in the *Científicos de la Basura* program. **(A)** Schoolchildren from "San José Rama Blanca" Educational Institution in La Gomera, Guatemala, sharing their research results with the educational community in 2019; **(B)** Schoolchildren from "República de Suecia N° 20959" school in Cañete, Peru, perform a representation with plastic bottles of the protagonists of the storybook "La Hermandad de las Tortugas" in 2019; **(C)** Peruvian national newspaper published in 2020 a press note written by schoolchildren of the "Beata Imelda" Peruvian-German School of Lima, Peru (link to the note: https://elcomercio.pe/corresponsales-escolares/historias/los-cientificos-de-la-basura-los-nuevos-guardianes-del-oceano-lima-noticia/); **(D)** Communication of research results by schoolchildren of "Modesto Sánchez Mayón" High School of Loreto, Mexico, in 2019. All images with corresponding permission.

not all teachers could participate in the same virtual meetings, and at least two separate videocalls (with 10–20 teachers each) were held. If a teacher could not participate in any of these group meetings, individual meetings were offered. During these videocalls, all the research steps were described in detail, and a virtual sampling was conducted that showed how to follow the research protocol in exactly the same way as it was required for their beach (e.g., showing a virtual beach with litter and counting virtual litter items). During the project period (2018–2020), we also conducted two *in situ* 1-week training workshops in Costa Rica (for ~20 teachers from Mexico and Central America) and in Ecuador (for ~20 teachers from Panama, Colombia, Ecuador and Peru). During these workshops, the teachers learned to conduct all the samplings to be developed during the project.

### 2b) Guidance for teachers during research

The citizen science coordinators maintained regular contact with the teachers during each project period (Figure 2), and they carefully monitored the progress of each teacher with their schoolchildren. For these individual communications, the coordinators used email, WhatsApp, phone, or videocalls, depending on the needs and preferences of each teacher/collaborator.

When the field sampling approached, the citizen science coordinators reviewed with each teacher the main steps for the research to ensure that teachers and their schoolchildren were well prepared for the research activity. During this period, the coordinators communicated with the teachers primarily through WhatsApp to enable rapid interaction. The coordinators knew the exact day and hour when each teacher did their sampling, and they made an effort to be available during those hours to respond instantaneously via WhatsApp for any consultations that would come up during the sampling. Upon completion of the research, the coordinators sent brief messages to the teachers and their schoolchildren congratulating them for the successful completion of the field sampling. When data were received, these were immediately checked for completeness and correct labelling (very similar to the process described by Dittmann et al., 2022). If there were substantial delays in data transfer (e.g., because the teachers were too busy with their regular schoolwork), the coordinators contacted the teachers to request the data and offer assistance, for example, by processing images or revising datasheets for sufficient resolution. In all communications, it was emphasized that the research is only completed when all data had been received, checked and archived. Using this intense and personalized communication with each teacher, during the project years 2018 and 2019, we achieved high return rates (successful receipt of all data) of 80%–85% of all schools/teachers who had signed the participation agreement.

The main challenges occurring during the first 2 years of the work in the Latin American Network were climatic events (hurricanes or extended rainstorms in Central America), social unrests in Nicaragua, Colombia, Ecuador, and Chile, and the global health crisis (COVID-19 pandemic) (Figure 2), and the research projects had to be adapted to these external events. For example, weather-induced delays in the field research had to be accommodated (and the final evaluation/outreach activities could not be completed), and in the case of the social unrests in Chile, schools were not functioning and some samplings could not be conducted as planned.

### 3) Evaluation of data and sharing of results

#### 3a) Data evaluation and interpretation of results

After completion of the research and submission of the data, the citizen science coordinators supported the teachers in the analysis of the data. In addition to the working guides describing the steps to analyse the data, the teachers were provided pre-formatted Excel tables that allowed the schoolchildren to enter their data and visualize their findings in summary tables and figures, similar to other school projects. If suitable, the coordinators also provided data from other participating schools, to which the schoolchildren could compare their own findings. The working guides for data analysis and interpretation also contained questions that encouraged critical thinking about their findings, and reflection on possible causes of plastic pollution.

After the sampling, the program team evaluated all the (unvalidated) data and prepared a first report on the research findings. These reports were typically prepared within several weeks after receipt of the last dataset, and they were first shared with the teachers but then also made available to the general public via the program website (www.cientificosdelabasura.cl).

#### 3b) Guidance for communication

Following data evaluation and interpretation of results, the teachers and schoolchildren could advance to share their findings within their school or local community, or even with their scientific peers. Suggestions on how to participate in this scientific process were detailed in the evaluation/outreach guides and included science fairs, posters, and social media communications. The citizen science coordinators encouraged the teachers and their schoolchildren to choose the form of communication they felt most suitable (Figure 4). An instructional video provided hints about how to communicate their research findings (https://www.youtube.com/watch?v=A_QxnCiFPZM). If the teachers and their course decided to do this activity, the coordinator provided advice and shared information (e.g., from previous research projects of the *Científicos de la Basura* program) that could potentially be useful for the outreach materials the schoolchildren were preparing. Upon successful completion of the outreach event, the program team transmitted their congratulations to the teacher and their course. At the end of the research project all participating schools received a certificate of appreciation, which is sometimes requested and always cherished by the participants (see also Dittmann et al., 2023).

## Discussion

### Internal communications

The internal communications within the program teams are an essential element of all citizen science programs, which is especially true for school citizen science programs (see, e.g., Zoellick et al., 2012; Benichou et al., 2023; Bopardikar et al., 2023). Interestingly, in school citizen science programs on marine litter, the internal project interactions are rarely being mentioned when discussing the communication strategies of these programs. For example, Catarino et al. (2023) extensively describe the communication between the coordinating team and the schoolteachers and their schoolchildren. They also emphasize the outreach communication beyond their participating community, but they do not mention the internal communications within the coordinating team. Araújo et al. (2022) also focused on the communication between citizen science coordinators and the teachers, highlighting the importance of suitable materials and consideration of the learning objectives for the schoolchildren; it is evident that they paid close attention to the preparation of suitable materials and activities, but the internal conversations that certainly must have taken place were not explicitly mentioned. Also, van der Velde et al. (2017) highlighted primarily the training of teachers and schoolchildren without mentioning the internal communications within their team, but their study design had previously been thoroughly tested by professional scientists (Hardesty et al., 2017).

In this contribution we describe the close interaction between scientists and citizen science coordinators and selected teachers who evaluate and test the research activities. Several reports emphasize the importance of efficient communication between teachers and scientists (e.g., Zoellick et al., 2012; Atias et al., 2023a), which is essential to guarantee straightforward research activities that have an appropriate duration and are adapted to the motivation and capacities of schoolchildren (Bopardikar et al., 2023; Kali et al., 2023). This also ensures mutual benefits for teachers (learning goals) and scientists (contribution to research), which is essential for successful school citizen science projects (Kali et al., 2020; Roche et al., 2020). The activities initially designed by our program team (scientists, citizen science coordinators, teacher) have (i) led to multiple peer-reviewed publications providing marine litter baselines that are being used by decision-makers (e.g., Cristi et al., 2020), and (ii) been implemented by several other programs in Latin America and Europe (e.g., Kiessling et al., 2019), proving their usefulness and the value of the hard work during the design phase of the research activities. Another project used a comparable approach with direct interaction of the scientist in the classroom (Nicosia et al., 2014), where scientist and teacher formed a close alliance in order to guide one course of high school students in autonomous research. The authors describe their collaboration as follows: "In an effort to address the need for a guided framework, scientists and teachers participating in our study engaged in explicit discussions about the nature of science related to existing classroom curriculum. The purpose of these discussions was to create a starting point for the investigation." (Gray et al., 2012). We suggest to make these internal communications within the coordination teams more explicit because they are the foundation of most successful citizen science projects (Zoellick et al., 2012; Sagy et al., 2019; Atias et al., 2023b; Benichou et al., 2023).

Scientists participating in citizen science programs are often highly motivated, having strong intentions to return scientific insights to society while simultaneously contributing to scientific progress (Rambonnet et al., 2019). When scientists themselves have a strong interest in responding the scientific questions being investigated, the following evaluation and interpretation of the findings will have a higher probability to result in the advancement of knowledge (e.g., Nelms et al., 2022; Dittmann et al., 2023; Jadallah and Wise, 2023).

## Continuous communication with teachers

The citizen science coordinators from our program team are in regular contact with teachers and are always available to respond to questions during the main research phase. This is essential to guarantee the successful and correct application of the research guides, which is the first foundation for valid research data (see also Dittmann et al., 2022; Bopardikar et al., 2023).

The close involvement of the program scientists during the process also helps to resolve unexpected problems (e.g., due to climatic events) and take rapid decisions. For example, one consequence of the COVID-19 pandemic was that schools were not functioning and the research activities simply could not be conducted, similar as in a number of other citizen science programs during that period (e.g., Rose et al., 2020; Coldren, 2022). However, the strong sense of community in our project allowed us to develop alternative activities (e.g., Praet et al., 2023), and to readily restart activities when schools started to function again (e.g., Richter et al., 2021).

The intense communication between the citizen science coordinators and the teachers also leads to good knowledge about the professional and personal situation of each teacher. For example, the coordinators knew when climate or other external events led to delays in the realization of the learning and research guides, when a teacher was sick, and also when teachers conducted additional activities motivated by their participation on the network. The in-person training workshops created personal links and friendships among the teachers and scientists, promoting a feeling of community (see also Atias et al., 2023b). These personal relationships were especially relevant during the COVID-19 pandemic, when not only the program team but also many teachers faced unexpected challenges and personal hardship. Regular, appreciatory communication has also been shown to cause a stronger commitment by citizen scientists in other projects (Anderson et al., 2020; Rüfenacht et al., 2021; Nelms et al., 2022). It should also be highlighted that the citizen science coordinators have excellent interpersonal communication skills (confirmed by the evaluation surveys and personal conversations with the teachers), which helped to build and consolidate personal relationships among the program team and the teachers. These aspects are rarely being considered when discussing citizen science communications, yet they are the essential backbone of our network.

## Rapid evaluation of data and preparation of outreach materials/activities

One of the major challenges for many citizen science programs is the time between collection of the samples/data (meaning in many cases the active involvement of the citizen scientists) and the proper evaluation of the results, which is essential to answer the corresponding scientific questions. This process leads to long delays of approximately 3 years or more between data collection and publication (Christie et al., 2021) and citizen science projects are no exception to this (Dittmann et al., 2023). During the first 10 years of the program, the average time between completion of the research and publication of the results was approximately 2 years, but this period has increased since the program became larger (now involving schools from up to 11 different countries) and more rigorous data validation steps were implemented. Naturally, the teachers and their schoolchildren are very keen to learn about the findings of the collaborative research projects, just as in many other citizen science projects (e.g., Richter et al., 2021). The careful design of the research question and simple methods of data collection allow for rapid preliminary evaluation of the data, and the program team prepared brief reports in Spanish for teachers and schoolchildren within two to 3 months after the data-collecting period had ended (freely available at www.cientificosdelabasura.cl). These reports are also frequently shared with the general public via social media (Facebook, Instagram) and also traditional media (e.g., newspapers).

Teachers and their schoolchildren are also supported in evaluating their findings and planning and implementing actions, which typically are outreach events, such as science fairs, public talks, infographics, or social media posts. Sharing data with the general public (and not only among themselves) is an important motivation for many citizens who have participated in a citizen science project (Ferster et al., 2013; de Vries et al., 2019). Often the communication of results are done by the program teams (e.g., Le Coz et al., 2016; Catarino et al., 2023), but the citizen scientists themselves can be excellent communicators of the research findings and conclusions. The schoolchildren who participated in the research projects of the Latin-American Network were very interested in sharing their results with others, and they were very creative in preparing different outreach materials and activities (Figure 4).

While schoolchildren are willing to engage in outreach and taking actions about the litter problem, participation in citizen science programs only leads to marginal increases in pro-environmental behaviors (Oturai et al., 2022; Wichmann et al., 2022), similar as in other environmental education projects (e.g., Praet et al., 2023). This is generally attributed to the short period of participation, highlighting the need for continued engagement of schoolchildren (and other citizen scientists) in these activities (Oturai et al., 2022; Wichmann et al., 2022; Praet et al., 2023).

Sharing scientific findings with others can be highly empowering to schoolchildren (e.g., Dublin et al., 2014) or strengthen place-attachment in volunteer participants (e.g., Toomey et al., 2020). If schoolchildren are able to engage their families or local communities, there is even the potential to reach and positively influence a wider audience (Vaughan et al., 2003). Another positive aspect of engaging citizen science volunteers in outreach activities is that they self-identify stronger with "their" program and might be more likely to continue in future research studies (Rambonnet et al., 2019). In addition, the volunteers might reach specific stakeholders, which the program team might not easily reach, e.g., parents and local decision-makers (Vaughan et al., 2003; Rambonnet et al., 2019). If citizen science programs communicate effectively with decision-makers and other stakeholders, the probability that data and findings contribute towards the Sustainable Development Goals (SDGs) will increase substantially (Gacutan et al., 2023).

### Critical aspects of communication

The communication strategy of the *Científicos de la Basura* program is very labor- and time-intensive, which has several implications. The attention given to individual teachers means that the number of teachers that the citizen science coordinators can accompany in their research activities is limited, typically around 30 to 50 teachers. These numbers are far below those of other citizen science programs collaborating with teachers and schoolchildren, which can reach hundreds of teachers (e.g., Kiessling et al., 2019) or thousands of schoolchildren (e.g., Oturai et al., 2022). However, the strong personal bonds developed during in-person workshops and the research projects create a strong mutual commitment both in the program team as well as in the teachers (e.g., Rüfenacht et al., 2021). This was demonstrated during the COVID-19 pandemic when program team and teachers met regularly in videocalls (first on a weekly basis, later on a biweekly or monthly basis) offering mutual support during this time of personal hardship and professional stress, which especially many teachers experienced (Rasmitadila et al., 2020; Sigursteinsdottir and Rafnsdottir, 2022). During these meetings we occasionally discussed scientific publications on the marine litter problem and even invited colleagues from other countries to share some of their insights with the teachers from the network. After sharing concerns about the wellbeing of their schoolchildren during these meetings, one teacher was inspired by one of those publications (Schofield et al., 2020) and encouraged the program team to develop an app that allows schoolchildren to tell stories on the phone or computer; 80 schoolchildren then used that opportunity and shared their views and ideas about marine litter (Praet et al., 2023).

The intense communication between citizen science coordinators and teachers as being practiced by our program has important time requirements (e.g., Benichou et al., 2023; Jadallah and Wise, 2023), which may not be feasible for other citizen science programs. In the *Científicos de la Basura* program this approach has evolved over time, taking into account the high workload of teachers in Latin America. The close communication and careful adjustment of the research projects to the realities of the school teachers helps them in achieving the learning objectives for their schoolchildren. Certainly, there are still some difficulties that our program needs to overcome, such as incorporating professional communicators (i.e., journalists) and lowering the high personal strain on the fully committed program coordinators who often interact with teachers outside of regular working hours. Nevertheless, we suggest that other citizen science programs working in similar socio-economic environments might benefit from similar approaches to those employed in our program: engaging in close communication and receiving regular feedback from their volunteer collaborators, whether these come from schools or other societal backgrounds.

## Conclusion and recommendations

In this contribution we highlight the importance of internal communication within citizen science programs, especially the fluent dialogue between scientists and citizen science coordinators within the program team. The outcomes of these continuing interactions also strongly influence the communication with the teachers and schoolchildren (creating sense of community), and with the wider audience being reached by a citizen science program. The successful communication strategy of our program (internal communication and teacher communication) offers a number of advantages that could be recommended for other citizen science programs (Table 1), but it needs

**TABLE 1 Recommendations for communication processes in citizen science programs based on experiences in the *Científicos de la Basura* program that contributed to achieve the program goals.**

| |
|---|
| - Program team consisting of scientists, citizen science coordinators and a teacher, holding regular task-oriented meetings for efficient internal communication that guarantees successful research projects |
| - Focus on building strong personal relationships with participating teachers and therefore building a caring community supporting each other beyond the scientific goals of the program |
| - Conveying the worth of teachers' opinions, which not only enables to improve the research activities in the form of critical feedback, but occasionally leads to complementary activities |
| - Offer a mix of activities besides a core scientific activity the participants can be involved in, according to their interests, motivation and resources, for example, outreach activities or simply engaging materials such as an illustrated story book |
| - Offer activities that empower the citizen scientists and support them conducting these activities, e.g., outreach activity-guide |
| - Use communication tools that participants (in this case school teachers) are already familiar with. Use a variety of communication channels to adapt to the need of participants. Be readily available and have the team resources to be available |
| - Focus on the science: communicate the importance of the common research goal, emphasize that educational and scientific goals are interlinked in citizen science projects, and carefully listen to the participants in terms of need for assistance |
| - Use a ritual to convey the importance of being involved in the citizen science activity to all parties, for example, by signing a commitment agreement at the start of the project |
| - Prepare a preliminary research report as soon as possible (within 2–3 months of concluding the field research) as the participants are keen to learn about their collaborative findings |
| - Mutual praise between all parties involved, here among the program team, teachers and schoolchildren |
| - Emphasize the need for continuous and sufficient financial resources towards funding agencies as an established and dedicated citizen science community requires intensive communication at different levels |

to be kept in mind that this strategy is highly labor-intensive, which requires substantial time and financial resources (personnel costs). In countries with other socio-economic backgrounds where teachers may have more time to prepare their classes and thus have better opportunities to integrate new materials, citizen science programs might work with less communication. However, in order to generate a sense of community, strong commitment and even willingness to change behaviors (e.g., related to plastic consumption), intense communication between program teams and volunteers might be required.

It should also be emphasized that the intensive and personal, customized communication as practiced in our program results in strong commitment of the participating teachers, which is also reflected in a significant personal commitment of the program team. We conclude that communication and commitment are closely related to each other and build the foundation of successful citizen science programs.

## Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

## Author contributions

MT: Conceptualization, Funding acquisition, Supervision, Visualization, Writing–original draft, Writing–review and editing. JB: Writing–review and editing. MD: Writing–review and editing. DV: Writing–review and editing. SD: Writing–review and editing. VG-T: Writing–review and editing. GA: Visualization, Writing–review and editing. DH: Visualization, Writing–review and editing. TK: Visualization, Writing–review and editing. AL: Writing–review and editing. N-LX: Writing–review and editing. PN: Writing–review and editing. JS: Writing–review and editing. NV: Writing–review and editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



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# More complex than expected—mapping activities and youths' experiences at BioBlitz events to the rosette model of science communication

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Deficit, dialogue, or participation—which of these three main models of science communications is the best fit to describe activities and experiences of citizen science? One might assume that participation is the best match, but the reality of citizen science events is more complex. The rosette model of science communication offers a more detailed set of subcategories, e.g., educate, entertain, or do, in addition to the three main models—deficit, dialogue and participation. To systematically describe citizen science activities and experiences, we apply data on what activities are offered and what young people (5–19 years old) experience when participating in a citizen science event format called BioBlitzes across the rosette model. The mapping results illustrate how the rosette model can help to make citizen science project designers and practitioners more aware of the various modes of science communications that they may encounter at BioBlitz events and inform their design decisions regarding how settings can shape participants' experiences.

KEYWORDS

**science communication, citizen science, communication model, science education, community science**

## 1 Introduction

In recent years, opportunities for participation in citizen science (CS) have rapidly increased. However, the definition of CS and the term itself are still a topic of debate (e.g., Cooper et al., 2021) and ongoing negotiation within the community (Haklay et al., 2021; Haklay, 2023). The most common denominator may be that its "common, shared goal is to collect and analyze information that is scientifically valuable" and that this "distinguishes citizen science from areas such as experiential learning or environmental education" (Hecker et al., 2018, p. 2). Different typologies of CS projects co-exist (e.g., Shirk et al., 2012; Haklay, 2013), commonly they use the extent of citizen scientists' participation in the scientific process as a key indicator, for example, to determine whether a project is "contributory" or "co-created" CS. Considering the historical development of science communication models, three main models can be identified: 1) the one-way communication of the deficit model, 2) the two-way communication of the dialogue model or 3) the participation model with multiple interactions and sources of information and knowledge. Based on these three

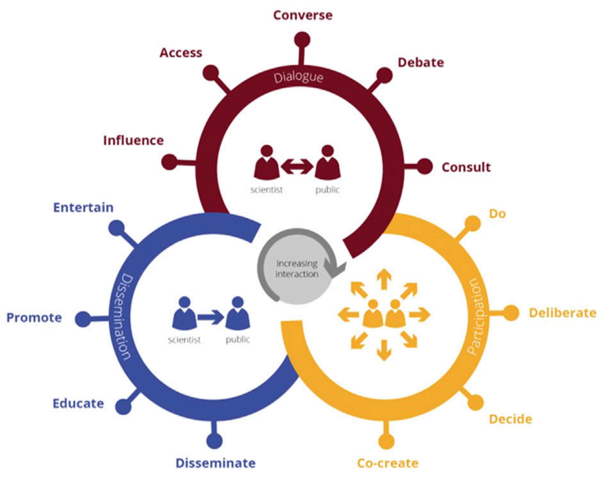


FIGURE 1
The rosette model of science communication (Metcalfe 2019), adapted according to an interview with Jenni Metcalfe on the Telling Science Stories Podcast (Fleerackers, 2023), adapted design by Lutz Kupferschläger).

communication models deficit, dialogue, and participation, one might assume that all experiences of citizen scientists within CS projects can simply be categorized as one type of science communication, as participation. But does participation best and sufficiently reflect the intended opportunities of CS projects and the actual experience of CS participants? Zooming in on a particular science communication model, do all interactions fall in the "Participation—Do" category of the rosette model of science communication (Metcalfe, 2019; Figure 1) or is the reality more complex? In this perspective article, we explore the benefits and the limitations of using the rosette model of science communication to map activities and participation of CS. We use a specific type of CS events, so-called BioBlitzes, as examples and use data that was collected to explore youth participation and learning through CS participation in the LEARN CitSci project to assess the approach.

## 2 The role of science communication and the development of the rosette model

The history of science communication can be told through the development of the three main communication models: deficit, dialogue, and participation. Starting in the 1980s with concepts such as the Public Understanding of Science (Royal Society, 1985) focusing on the deficit model, a one-way communication from science experts to the public. Then it shifted to the concept of public engagement with science in the early 2000s, stressing the need for two-way communication and a dialogue model for science communication (e.g., House of Lords, 2000). More recently, participating in science and participatory science communication have gained popularity (e.g., Hetland, 2021; Bucchi and Trench, B. 2021; Metcalfe et al., 2022). Science communication models describe "how science has been, is being or should be communicated" (Metcalfe, 2019, p. 9), however, as in many other disciplines there has been a research-practice gap. In this case, the developed models have been discussed by science communication scholars but only a few studies investigated their relevance and occurrence in science communication practice (e.g., Brossard and Lewenstein, 2010; Jensen and Holliman, 2016). Building on the models in science communication theory and considering the results of her empirical studies conducted with science communication practitioners, Metcalfe developed three science communication models (2019): the spectrum model, the rosette model, and the nexus model of science communication. The spectrum model presents deficit, dialogue, and participation as a linear progression, conveying a hierarchical structure and is less detailed than the rosette model. In comparison, the nexus model is more complex and moves beyond deficit, dialogue, and participation. It separates six different science communication actions (access, respond, persuade, consult, converse, participate), audiences (latent, activist, civil society, concerned groups, institutional, interested publics) and respective desired outcomes. To focus on activities and participants' experiences in citizen science, the rosette model seems to be the best option, as it recognizes that "while the stated objectives of a science communication activities may align with one of the three science communication models, features of all three science communication models co-exist and complement each other in many science engagement activities" (Metcalfe, 2019, p. 180).

The science education and science communication as well as the citizen science community are still debating commonalities and borders between science communication and science education (Baram-Tsabari and Osborne, 2015; Roche et al., 2020). The rosette model offers a way forward through this discussion, potentially because its visualization works as a useful tool to illustrate the three main science communication models and subcategories to characterize different science communication formats at one glance. Since it includes "Educate" as a subcategory, education can already be considered included in the model, but the model can also be used to reflect on other formats that science educators or education researchers already use in their repertoire that go beyond the classic format of educating, e.g., entertaining or disseminating. Additionally, it enables conversations about other modes of science communication that they might try to apply in their work. Similarly, the citizen science community may feel represented through the "Participation—Do" subcategory.

## 3 BioBlitzes

BioBlitzes are popular CS events focused on Biodiversity monitoring. They are described as "a collaborative race against the clock to discover as many species of plants, animals and fungi as possible, within a set location, over a defined time—usually 24 h" (Robinson et al., 2013), but this definition has evolved to also include much shorter periods. BioBlitzes typically fall into the category of contributory CS (Shirk et al., 2012), as their scientific aim is to generate biological records (Isaac and Pocock, 2015) with the help of experts and non-experts that can be used for scientific or monitoring purposes.

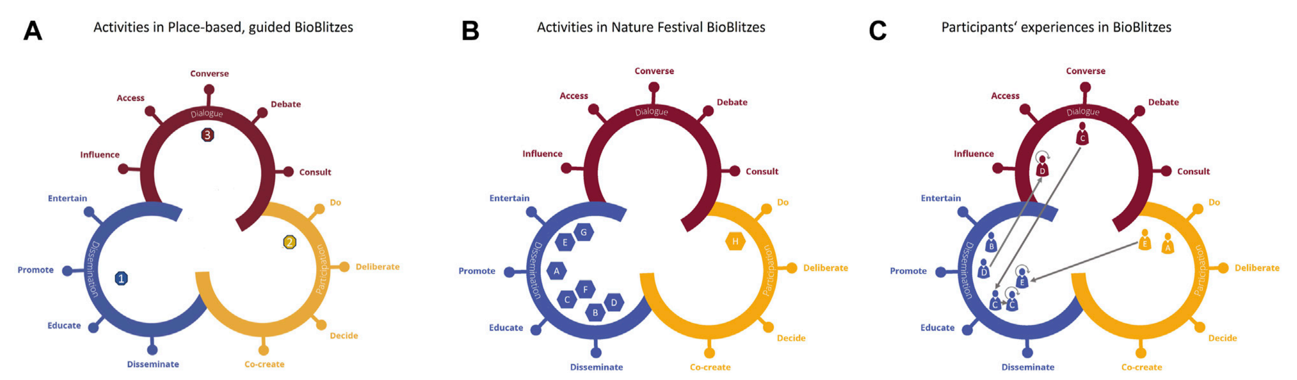


FIGURE 2
**(A)** Activities of "Place-based, guided BioBlitzes" mapped to the rosette model of science communication, **(B)** Activities of "Nature Festival BioBlitzes" mapped to the rosette model **(C)** Examples of youth participants' experiences mapped to the rosette model [adapted from Metcalfe (2019), design by Lutz Kupferschläger].

# 4 Data collection

In 2018, our first year of the LEARN CitSci project, we observed 14 BioBlitzes led by the Natural History Museum in London, the California Academy of Sciences (San Francisco) and the Natural History Museum of Los Angeles County that lasted between 2 and 9 h. Following the BioBlitz typology of Meeus et al. (2023), seven of the observed BioBlitzes can be categorized as place-based, guided BioBlitzes. The seven others were place-based, guided general (monitoring any kind of biodiversity) or guided targeted (focused on a specific taxon, e.g., bats or insects) BioBlitz activities that were run within a Nature Festival setting. For this article we will call the first type "Place-based, guided BioBlitzes" and the second type "Nature Festival BioBlitzes."

We used Cultural-historical activity theory (Engeström, 2000) to guide our observations for capturing setting characteristics and youth participation. The activities of the event, resources, rules, tools, and people involved were documented in a detailed written broad setting description. In addition, we used field observations (Emerson et al., 1995) to capture data about the participation of 91 youth. Analyzing the field notes, we identified key action/interaction episodes youth experienced during BioBlitzes. For each key action/interaction episode, we wrote a memo containing a claim about youth participation, a description of the type of participation observed and excerpts from field notes as evidence to support the claim (for more details on the LEARN CitSci data collection, analysis and results see Lorke et al., 2021; Ghadiri Khanaposhtani et al., 2022).

# 5 Mapping the activities

Based on the broad setting descriptions we can map the activities planned and run at the CS event and illustrate the range of different science communication formats and modes of communication offered at a BioBlitz. Since we are not interested in comparing single events, we pool the data for the two BioBlitz types that we observed in our study: "Place-based, guided BioBlitzes" and "Nature Festival BioBlitzes."

The "Place-based, guided BioBlitzes" were run according to a "sandwich model", wherein they started with an introduction for the whole group (See Figure 2A, octagon labelled 1), then usually smaller groups went out into nature to explore and collect data using the iNaturalist app to create records of their findings (Figure 2A, 2) and the event ended with some form of sharing results and reflecting on findings (Figure 2A, 3), (though many of the events also allowed people to join later or leave earlier). The introduction explained the goal of the day, the purpose of the BioBlitz, the use of iNaturalist and any information regarding basic needs as well as safety rules for outdoor activities. Some events entailed a short practice session, to ensure who wishes to knows how to record observations on iNaturalist. Many events required participants to sign up ahead of the day but often remained flexible to include people who opted to join on the day.

The "Nature Festival BioBlitz" events offered a wide range of activities: live animal presentations, stalls showcasing the work of partnering nature-related or community-based organizations (see Figure 2B, octagon labelled A), presenting museum handling collections (pelts, fossils, insect, spider, lizard, snake, bat and snail specimens) (Figure 2B, B), offering microscope activities (Figure 2B, C), showing slideshows (about iNaturalist, the historic development of the local area) (Figure 2B, D), nature crafts activities (Figure 2B, E), iNaturalist tutorials (Figure 2B, F), a nature-themed puppet theater show (Figure 2B, G), and activities focusing on exploring and recording biodiversity such as pond dipping and nature walks (Figure 2B, H) (some themed as a bat walk, Slime, bug hunt, etc.). Some activities were scheduled, and others were available throughout the entire day. Only activities outside of the usual opening hours, namely, the bat walk, required registering; the other activities were provided as drop-in events.

# 6 Mapping experiences

To demonstrate the utility of the rosette model for analyzing citizen science activities, we mapped the observed youth experiences from our field notes and memos onto the rosette model of science communication. This allows us to illustrate the variety of science communication interactions that youth experience during a BioBlitz. For this demonstration purpose, we have chosen five examples (using pseudonyms) from our sample that enable us to show a broad range of different experiences (see Figure 2C):

> A—Nia is on an iPhone alone, taking a picture of a tree and uploading it. She scrolls through the options for identifications and chooses one [. . .] Nia takes a picture of the moss and uploads it to iNaturalist. (Female, elementary school-age, SF BioBlitz)

The young person is participating in the citizen science activity: Participation—Do

> B—Instructor: "Let's call them out," Together (Instructor, Tim, and the whole group) chant, "Squirrel, Squirrel, Squirrel" Gigi moves from a tiny chair onto the floor to crawl towards the puppets. The instructor explains how squirrels communicate with their tails and stomp their feet. Tim's eyes are locked on the puppets as he continues his migration from the back of the room to now squeezing through kids to get to the front row. (Male, elementary school-age or younger, L.A. BioBlitz)

The young person is attending the nature-themed puppet theater show: Dissemination—Entertain

> C—Dean looks at the insect specimens in resin blocks that are on display (the task is to sort the specimens into groups). Educator: "Are you up for a challenge today? What do you think this is?" Dean points at specimens and identifies them as: "Arachnids," then goes on to "Scorpion" "Spider" The educator nods in agreement: "Try the beetles—Try to work out how scientists know that a beetle is a beetle!" Educator What is it? FY: Ladybird AL: Can ladybirds fly? FY: Yes. (C1) AL: "Where are the wings? The wings are underneath. To be a beetle you need to have a line on the back. Science isn't always easy. We have 350 scientists at the Natural History Museum." Dean looks at them using a magnifying glass to spot the line on the back of the specimens and sorts them into piles according to whether he can see a line on their back or not. (C2) Dean then talks to his sister: "This is definitely an insect, there is a line" points out the line on the insect's back for her to see. Educator: "Good sharing of information!" (C3) (Male, primary school-age, London BioBlitz)

The young participant can share his knowledge in a conversation with the educator, then the educator teaches him how to identify if a specimen is a beetle or not and the boy then goes on and shares his new knowledge with his little sister: C1 = Dialogue—Converse → C2 = Dissemination—Educate → C3 = Dissemination—Educate (role switch)

> D—Scientists asked all participants to care for the intertidal zone by making sure that organisms went back to places where they were found and to limit harm to the organisms (D1). Lilly to her cousin, M3, "Don't step on the little volcanoes!" Lilly seems panicked. The educator explains to Lilly's mom that Lilly meant all the barnacles and limpets on the rocks and how their body shapes do look like little volcanos. (D2) (Female, primary school-aged, L.A. BioBlitz)

The professional scientists at the event promote responsible behavior in a natural habitat and the youth participant later insists that her cousin does not harm the barnacles and limpets: D1 = Dissemination—Promote → D2 = Dialogue—Influence (role switch)

> E—A young man records his own findings using iNaturalist (E1) and then educates others, "You can ID or you can just take the picture if you're not sure and someone can help you. [. . .] You can still upload even if you don't know." (E2) (Male, high school-aged, L.A. BioBlitz)

The young person participated in citizen science and then taught another participant how to record observations on iNaturalist: E1 = Participation—Do → E2 = Dissemination—Educate (role switch)

Three of these examples (namely, C, D and E) show that the original description of communication in the rosette model as scientist to members of the public, does not match the interaction in citizen science completely. The model was not intended to cover this aspect but can be adapted easily to highlight when such role changes occur. We chose to add a switch symbol to indicate the changed role.

# 7 Discussion

The mapping shows that the rosette model provides a straightforward way to show which modes of science communication are covered by the offered activities. Comparing the two types of BioBlitz events, the "Nature Festival BioBlitzes" offers more varied activities, while the "Place-based, guided BioBlitzes" takes a more structured and focused approach. This seems reasonable, considering the differences in audience recruitment. Commonly, the participants of the "Place-base, guided BioBlitzes" register for the event or attend intentionally. So, it is highly likely that they already are somewhat familiar with the purpose of the citizen science event. In contrast, the "Nature Festival BioBlitzes" with their wide range of activities appear to be tailored to a broad audience. They can attract participants that not necessarily intend to take part in citizen science, entertaining, disseminating or educating activities by offering a low-risk entry point for participants. This may encourage them to engage in more activities and maybe even contribute to citizen science. In hindsight, this all may sound very logical, almost obvious, however, mapping activities across the rosette model can serve as an easy visualization technique to support citizen science event or project planning. Citizen Science often is a collaboration of multi-professional teams with varying experience in science communication. While other, more complex frameworks for science communication in citizen science exist (e.g., Hecker and Taddicken, 2022), having the activities overview available in one visualization is a huge benefit of the rosette model. This may help to quickly identify gaps in the offered programming, clarify people's roles, leverage people's expertise, and define objectives for each activity as well as for the overall event.

There is a current trend to "dissect" citizen science project activities to deepen our understanding of the individual participant experience, their participation, their interactions, the resources, and opportunities they use or do not use within a given citizen science setting (e.g., Phillips et al., 2019; Golumbic et al., 2020; Lorke et al., 2021; Ghadiri Khanaposhtani et al., 2022). This seems crucial to provide insights into what elements of citizen science are responsible for achieving learning outcomes ranging from interest to knowledge and skills to developing self-efficacy, agency, or engaging in identity work. Hence, mapping activities can clarify which activities are offered, but mapping participation, as shown in Figure 2C, can be one method to reveal participants' pathways and their varied encounters within the setting. Here, we showed this only for a few examples and to illustrate the possibilities of mapping to this model for CS. A more in-depth mapping may enable researchers or evaluators to better understand the participants' pathways throughout the event or project and maybe reveal how best to purposefully guide participants through complex settings, such as the "Nature Festival BioBlitzes", towards the citizen science "Participation—Do" activities.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

## Ethics statement

The studies involving humans were approved by The Open University Human Research Ethics Committee (HREC/2726/Herodotou) and UC Davis (IRB 624197-4). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and institutional requirements.

## Author contributions

JL: Conceptualization, Writing–original draft, LR: Funding acquisition for LEARN CitSci, Writing–review and editing, HB: Funding acquisition for LEARN CitSci, Writing–review and editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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# We want you! Recruitment strategies for the success of a citizen science project on urban wildlife ecology

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In this case study, we report on the recruitment of participants for a citizen science (CS) project on urban wildlife monitoring (about 860 participants), and the consequences of recruitment strategies for achieving the project goals. We describe the approach that we used to identify our target audience and to design the core message for the recruitment campaign. We searched for participants who were interested in wildlife and in the scientific research process. We based the recruitment campaign on the appeal of discovering wildlife in people's immediate surroundings. Recruitment was successful in terms of the number of applications we received. Participants' interests reflected their focus on wildlife, and we discuss how this was reflected in their engagement. We use this case study to highlight the importance of deliberately designing recruitment strategies for CS projects. Such strategies will have implications for participants' motivation and ultimately may influence their contributions to the project.

KEYWORDS

**citizen science, recruitment, interest, wildlife, participation**

## 1 Introduction

Effective science communication has become increasingly important to counter phenomena ranging from fake news and misinformation over conspiracy theories and beliefs to vaccination skepticism. To increase trust in science and emphasize its important role for society, citizens may need to learn more about science and get involved with its processes (Bromme and Goldman, 2014). One way for citizens to do so is to engage in citizen science (CS) projects. These are projects in which volunteering citizens participate in scientific research projects and collaborate with scientists (Bonney et al., 2009; Heigl et al., 2019). Yet, finding citizens who volunteer to engage with scientific research projects can be challenging and different recruitment strategies have been suggested (Andow et al., 2016; West and Pateman, 2016; Crall et al., 2017; Fischer et al., 2021). In this case study, we report on the suitability of a recruitment campaign of a CS project on monitoring urban wildlife.

Through digital technologies, increasingly diverse CS projects are available for citizens to participate in (Preece, 2016) on a growing number of online platforms (e.g., www.zooniverse.org, Cox et al., 2015; www.ispotnature.org; Silvertown et al., 2015; www.inaturalist.org; Aristeidou et al., 2021). These platforms feature projects from a diverse spectrum of disciplines, from environmental science through astrophysics and chemistry to literature and the arts. On the one hand, CS is an immense support for scientists in gathering extensive data sets and carrying out large scale research (Cooper et al., 2007; Cohn, 2008). It is also a valuable means to increase the societal relevance of scientific research (Hecker et al., 2018). On the other hand, participating in a CS project can be beneficial for the volunteering citizens, as they may gain knowledge about new topics and the scientific research process. Moreover, they can benefit from other individual outcomes, such as learning new skills, exploring scientific data, sharing experiences with other citizens and scientists, and gaining a sense of scientific self-efficacy (Phillips et al., 2018; 2019). In this sense, CS offers great potential for science communication, because in CS projects research and communication are not separate processes, but closely intertwined (Wagenknecht et al., 2021). Through interactions between scientists and citizens, the target audience essentially becomes involved in the communication process itself (Giardullo et al., 2023), thus moving communication beyond mere dissemination of project results (Gascoigne et al., 2022).

In this manner, CS can be a tool for science communication. Conversely, science communication is a key component for successfully recruiting, retaining, and motivating citizen scientists (Baruch et al., 2016; Wagenknecht et al., 2021). Since communication strategies shape the expectations associated with CS in general and specific projects in particular, they need to be well thought out and appropriate for the level of participation (Gascoigne et al., 2022). For those CS projects created by academic scientists, the success of the scientific research endeavor depends on citizens' involvement - that is, a sufficient number of citizens must be willing to participate and engage in the project tasks. Therefore, the successful recruitment of volunteers is essential for the overall success of CS projects (West and Pateman, 2016; Fischer et al., 2021), and communication is the key tool needed to achieve this (Hecker et al., 2018; Golumbic et al., 2020). In order to develop a recruitment campaign, it is necessary to understand who would potentially be willing to participate in a CS project and why this is the case (e.g., Füchslin et al., 2019). Then, it is essential for the success of the project to tailor communication to reach the various interest groups (Wagenknecht et al., 2021). For this purpose, it is important to define the target audience and to understand their interests, demographics, and motivations. In their marketing messages, scientists need to create clear and compelling content that highlights the benefits and impact of a CS project and emphasizes how participants can contribute to scientific research, make a difference, or acquire new skills.

Recruitment does not merely aim at attracting a large number of people—it aims at generating interest among specific target groups with the appropriate type of messages and campaigns (Brouwer and Hessels, 2019). Although it may be evident that people will only spend their leisure time on activities they like, Hart et al. (2022) argue that this approach has not been sufficiently built into the development of CS projects. In terms of recruitment, it is vital to target potential participants whose interests and motivations match the project goals, since only then they will contribute actively and continuously. Therefore, project organizers need to consider potential participants' interests, circumstances, and demographics, and how they will become aware of the opportunity to participate (West and Pateman, 2016). However, as many scientists have not received training in science communication, many CS projects do not approach the recruitment of volunteers systematically and pay little attention to the required types of messages (cf. Brouwer and Hessels, 2019). Therefore, there is a need for studies on the relevance of appropriate recruitment strategies for the success of CS projects.

In the study presented here, we report on the recruitment of participants for a CS project with about 860 participants. First, we aimed at identifying specific target groups. We then investigated which specific marketing tools of the campaign were particularly effective in recruiting new applicants for the project. We also aimed at understanding the influence of the recruitment campaign on the selection of citizens who applied to participate in the project, their motivation to participate, and their actual contribution to different project tasks. This case study describes the development of the recruitment campaign, taking into account the project goals and design, and the evaluation of the campaign using data from applicants' online application forms as well as page views on the project's web page after certain recruitment measures were implemented. In this way, we were able to base the assessment of our recruitment success on both subjective and objective data.

## 2 Project and applicants

The study was conducted as part of an interdisciplinary research endeavor aimed at elucidating to what extent CS can be used as a tool for science communication. Different CS projects were evaluated regarding participants' individual learning outcomes, emotions, and attitudes (Greving et al., 2020; 2022; 2023; Bruckermann et al., 2021; 2023). Here we present data from a CS project that monitored terrestrial wild mammals in private gardens (i.e., yards that were only accessible by the owners, tenants, or leaseholders and persons living in the same household) in Berlin, Germany, in a standardized manner to analyze spatial and temporal interactions among wild mammal species. In addition, we examined what habitat features in gardens affected the occurrence of wildlife. The CS project was carried out between fall 2018 and fall 2020 in five rounds with the same procedure and content. Each project round lasted a total of approximately two months. Citizens who were interested in participating in this project applied online. Participants were selected on the basis of a systematic sampling grid that consisted of 287 square cells (2 × 2 km each) covering the whole city of Berlin plus adjoining areas. Citizens accepted to the project received a wildlife camera for data collection on loan. The number of participants was limited to 200 per round, corresponding to the number of cameras at our disposal. Each participant could only participate in one project round. Over the course of the project, 74% of the grid cells were sampled with a camera at least once.

In each round, participants received a wildlife camera as well as information about the installation of the camera and data collection. Apart from these offline activities, participants performed all other activities on an online platform that was exclusively set up for this CS project. During the data collection period of four weeks, participants were asked to upload the images from the wildlife camera onto the platform. In addition, they were provided with extensive background information on wildlife in urban areas. They were then asked to identify the species of animals captured in the images, both in their own and in images taken by other participants. To ensure data quality, species identification was only considered valid when two participants identified the same species. When assessments differed, the image was forwarded to the project scientists who then identified the species. Furthermore, the platform provided a guided tool for participants to graphically display and statistically analyze both the data from their own gardens and the complete dataset of all participants. They also had the opportunity to discuss their results in a forum. Participants had to collect data with their wildlife cameras and assess images on the platform; reading information and analyzing data were optional. Data collection with the cameras was conducted by the participants only, while the evaluation of the images on the platform was supported by the project scientists. Participants' activities on the online platform were tracked by an open source web analytics application for website traffic tracking (Matomo v3.9.1), and the results were published by Bruckermann et al. (2022). Approximately 300,000 wildlife camera images were uploaded by participants, 40,000 of which documented wild terrestrial animals and 34,000 domestic cats. The most common wild species were foxes, raccoons, hedgehogs, and squirrels. The species interactions of the mesocarnivores red fox, marten, raccoon, and domestic cat were analyzed (Louvrier et al., 2021).

# 3 Target groups and recruitment campaign

In accordance with common procedures in marketing and science communication (e.g., Hart et al., 2022), we identified the target groups in three steps (e.g., Rüfenacht et al., 2021): i) Defining relevant groups, ii) analyzing their perspectives and interests, and iii) mapping their interests onto the project objectives. We then designed the recruitment campaign accordingly.

i) **Defining relevant target groups:** Based on our project goals, we were looking for adult citizens with a private garden. Furthermore, these citizens needed a computer and internet access, as they performed all steps of the project except data collection online.
ii) **Analyzing perspectives and interests:** We used an approach often applied in marketing and design thinking to analyze the interests of our target groups: Developing personas. Personas are fictional characters (i.e., with certain ages, occupations, and interests) representing different target groups (Chang et al., 2008; Nielsen, 2019). These characters help to understand the target groups' needs, behaviors and interests. One key interest we identified was the opportunity to learn about wildlife. Another possible interest was to interact with scientists and other participants. Finally, citizens could have also been interested in contributing to science and analyzing data.
iii) **Mapping interests to project objectives:** Following the analysis of citizens' interests, we linked these interests to the project goals which were: a) Collecting high-quality data about terrestrial mammals, and b) providing citizens with the opportunity to learn about the content and processes of scientific research. Therefore, we needed a large number of volunteering citizens who were willing to engage in all steps of the project.

## 3.1 Conducting the recruitment campaign

Based on the first three steps, we identified three options for the recruitment campaign: a) A message that appealed to a broad audience for maximum attention, b) a message that addressed a scientifically interested audience, or c) two different messages for these two target groups. All three options had advantages and disadvantages. Since the success of the project hinged on attracting a large number of participants—i) in order to cover large parts of the city area to obtain representative data on urban wildlife, and ii) for our study on the suitability of CS as a tool for science communication—we based our decision on the argument that we needed maximum attention for our campaign. Thus, we chose the message for the broad audience (see Figure 1).

We used this message in a broad range of common marketing formats. These were as follows:

- **Press releases:** At the start of the application period for each project round, we issued a press release with information about the research project and participation. The press release was distributed by the institute conducting the study in Berlin, using distribution services such as dpa (German press agency), idw (information service science), AlphaGalileo, and EurekAlert. It was additionally posted on the institute's website.
- **Project newsletter:** An e-mail newsletter was sent to interested people who had registered for it on the project website. The newsletter contained news from the project and information about the next project rounds and the application process.
- **Interviews and features on radio and television**: Especially in the first project rounds, the press releases were taken up by local media.
- **Posters in transit places:** At the start of the application period for project rounds 1, 3, and 4, we put up posters with two designs (see Figure 1) in train, tram, and bus stations.
- **Flyers and postcards:** We distributed flyers and postcards at public events visited by citizens interested in science (e.g., so-called "Long Night of the Sciences" in Berlin) and to private homes.
- **Newspaper articles:** Following press releases, the project was subject of a number of newspaper articles.
- **Advertisement in a local weekly newspaper:** At the start of the application period of rounds 3–5, we placed advertisements in local newspapers.
- **Announcements on websites:** On specific websites relevant to our target groups, like gardeners, we announced the start of each round of our project.

We did not run a social media campaign (cf. Crall et al., 2017; Brouwer and Hessels, 2019) because our target group of garden owners was likely to be older than, for example, participants in app-based crowdsourcing projects, and therefore less social media savvy.

In most marketing formats given above and depending on the scope of the format, detailed information on the requested time


FIGURE 1
Posters used in the recruitment campaign (Copyright: IZW). Both designs were based on the appeal of discovering wildlife in one's garden. (Text on the poster translated into English: Gotcha! Discover the secret life of your animal neighbors with a wildlife camera. We are looking for curious citizens with gardens in Berlin for a two-month research project. For more information please visit: project's web platform).

commitment for participants were given, for example, in the press releases and project newsletter, on the flyers, in interviews, and in newspaper articles. Additionally, all formats contained the reference and link to the project platform, where detailed information regarding the terms of participation was given. For instance, the level of time commitment was communicated to interested citizens using the statement: "If you are willing to invest about five hours per week for two months for your research activity." Moreover, it was openly communicated during the recruitment process that—corresponding to the number of cameras at our disposal—200 participants could be included in each round, and that we aimed to distribute the cameras as evenly as possible across the city area. Rejected applicants were told that they could apply again in one of the next rounds.

## 3.2 Effectiveness of the campaign and marketing formats

Recruitment was very successful in terms of the number of applications, as we received more applications for each round than we could allocate places for participants (max. 200 per round). In total, $N$ = 2,071 persons ($n_1$ = 595, $n_2$ = 249, $n_3$ = 300, $n_4$ = 685, $n_5$ = 242) applied for the project. The age of the applicants ranged from 19 to 89 years (mean 54.2 years, data from 2,059 applicants, invalid information from 12 applications was excluded). The large number of applicants in the first round resulted from the facts that the project was new, media interest was high, and we used all available marketing formats. The high number of applicants in round 4 may be due to the fact that this round was intended to be the last round and advertised as the last chance to participate. Only after that round, we decided to run round 5 to gather additional data. In round 5, we mainly contacted former applicants who had not been accepted in previous rounds and ran a very reduced recruitment campaign. Participants were selected primarily on the basis of the geographical distribution across the city.

To find out which formats were particularly effective in the recruitment strategy, applicants of rounds 3 to 5 were asked in the application form how they had heard of the project. Each applicant could give more than one answer (multiple choice question). Figure 2 shows the responses of applicants in rounds 3 and 4. Answers from round 5 applicants are not included because in that round we did not use all of the formats available from the recruitment campaign.

The results show that newspaper articles and posters in public spaces were the most effective marketing formats. Personal recommendations from family and friends also prompted a number of people to apply, which shows their importance as multipliers. On the other hand, TV and radio features and the distribution of flyers and postcards did not reach as many people as anticipated (e.g., radio feature, 4.4% in round 3, 6.6% in round 4). This may be related to the fact that TV and radio features are very limited in time (normally a few minutes) and also depend on factors such as the popularity and ratings of the radio or TV station, the day and time of broadcasting, and whether the feature is also posted online after broadcasting. The internet was given as a source by a relatively low percentage of mentions (8.5% in round 3, 11.8% in round 4), compared to newspaper articles and public posters. This may be explained by the fact that we announced the project on some relevant internet portals but not on social media. However, in some cases newspaper articles were also published online.

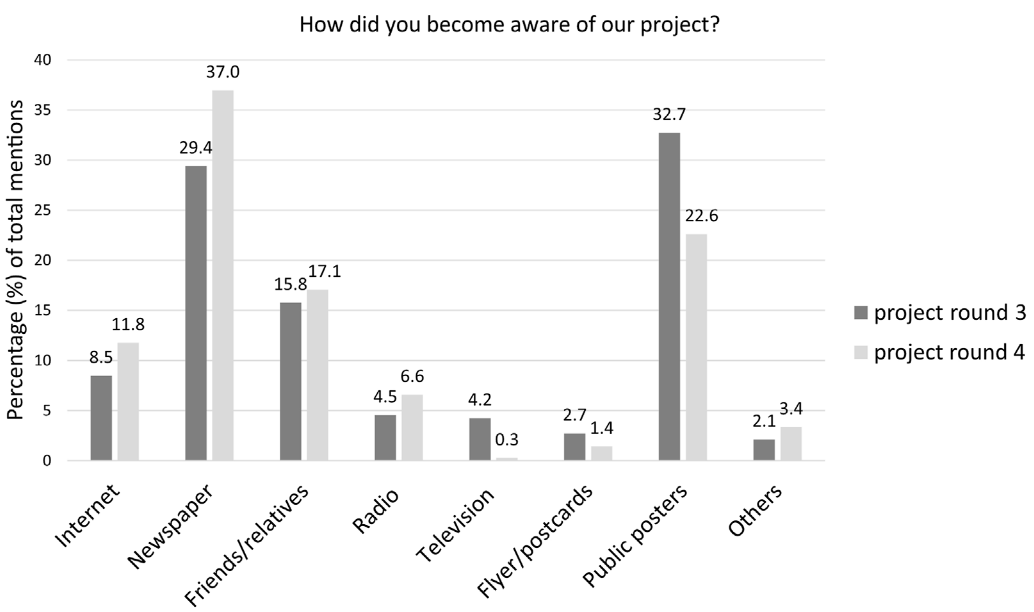


FIGURE 2
Information provided by applicants ($n$ = 300 in round 3, $n$ = 685 in round 4) on how they become aware of our project (via internet, newspapers, friends/relatives, radio, television, flyer/postcards, public posters, or other formats). Mentions per category are given as a percentage of the total number of mentions ($n$ = 330 in round 3, $n$ = 774 in round 4).

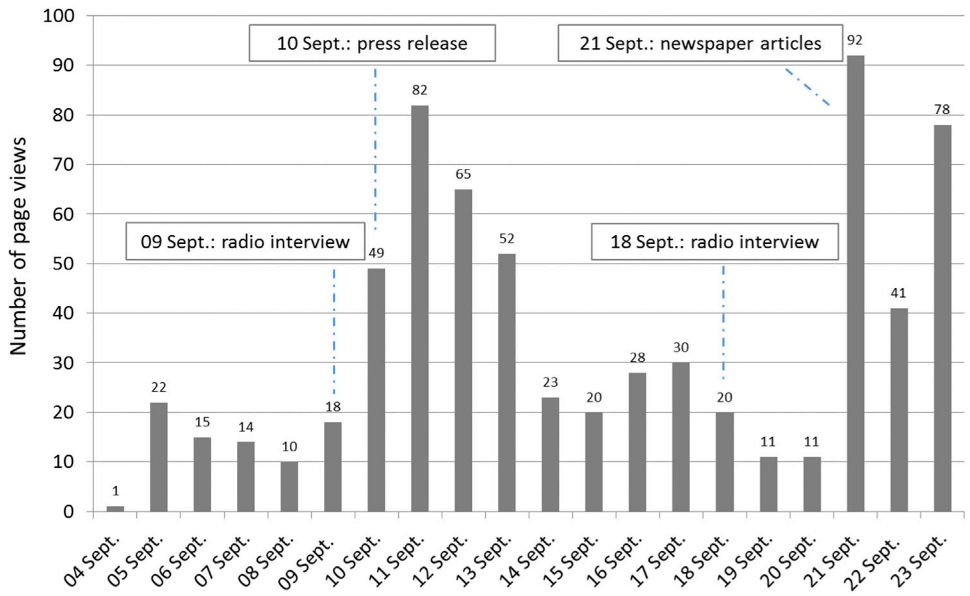


FIGURE 3
Number of page views per day of the public project's online platform over 20 days during the application period for round 1 (September 10$^{th}$ to 23$^{rd}$, 2018). The dates of the use of recruitment formats with high reach are indicated.

It should be noted that although the data in Figure 2 are presented per round, this does not reflect at what time of the project course applicants became aware of the project. It is also possible that applicants had already learned about the project through one format or various ones prior to the particular round for which they applied.

We tracked website traffic to the public project's online platform. As anticipated, page views increased (same day or next day) following the use of recruitment formats with high reach, such as press releases, newspaper articles, or radio or television reports (see Figure 3). For example, the number of

TABLE 1 Counts (in total numbers and percent) of content words and their synonyms given by applicants ($n$ = 1,775) in answer to the question "Why are you interested in putting up a wildlife camera in your garden?"

| Category | Content word | Synonyms (exampl.) | Count numbers | Percentage (%) |
|---|---|---|---|---|
| Wildlife | Wildlife | Animal(s) incl. wild animal(s) | 1082 | 61.0 |
| Place | Garden | House, property | 913 | 51.4 |
| Epistemology | Science | Scientific, knowledge | 343 | 19.3 |
| | Contribution | Contribute, contributing | 36 | 2.0 |
| | Analysis | Analyze, analyses | 13 | 0.7 |
| | Research | | 82 | 4.6 |

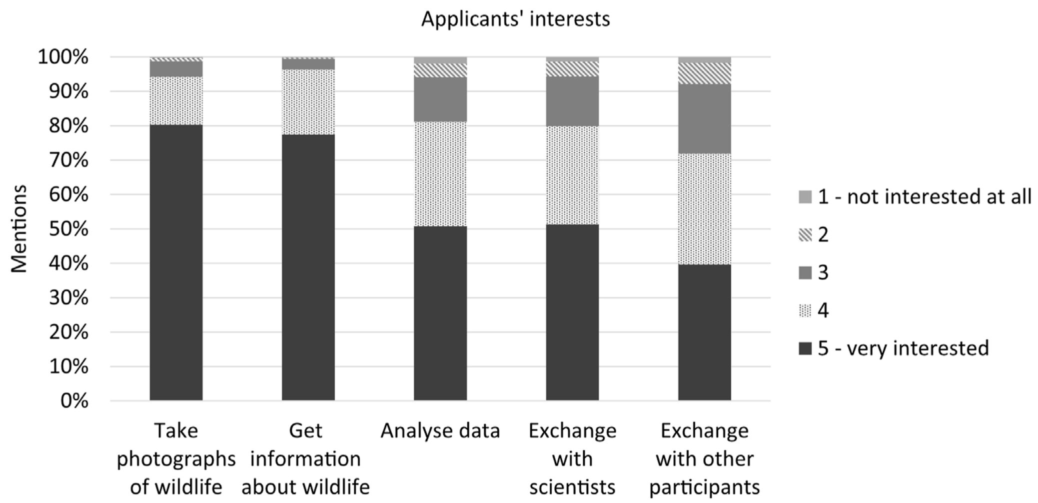


FIGURE 4
Applicants' interests to participate in the project across all five rounds on a 5-point scale ranging from 1 (not interested at all) to 5 (very interested).

page views was more than eight times higher on the day when a popular local newspaper published an article (92 page views on September 21st) than on the previous day (11 page views on September 20th).

## 3.3 Applicants' interests in participating

In order to investigate why applicants applied for the project, we asked them in the application form how much they were interested in five different reasons to participate (i.e., to take photographs of wildlife, get information about wildlife, analyze data, interact with scientists, interact with other participants) on a 5-point scale ranging from 1 (not interested at all) to 5 (very interested). Moreover, we asked them in a question with an open answer format for the reasons why they wanted to install a wildlife camera in their garden. All statements were screened by a human rater for specific content words and their synonyms (see Table 1). Then we counted how many applicants mentioned these words.

As shown in Figure 4, the results indicated that applicants were especially interested in taking photographs of wildlife (80.3% very interested and 13.9% interested) and getting information about wildlife (77.4% very interested and 18.9% interested). Applicants were less interested in analyzing data (50.8% very interested and 30.3% interested), interacting with scientists (51.3% very interested and 28.5% interested), and interacting with other participants (39.7% very interested and 32.2% interested). These results were consistent with the statements from the open question (Table 1). Here, most applicants specifically mentioned words related to wildlife or related to their house and surroundings. In contrast, words related to epistemology and involvement in the research process were mentioned much less frequently.

# 4 Discussion

Recruitment was very successful in terms of the number of applications we received, with the broad range of marketing formats and the visually appealing messages likely being key to this success. We conclude that different communication formats should be used in a targeted manner to achieve recruitment goals, taking into account the specifics of different formats such as target groups, reach, duration, and costs, as well as available financial and human resources. Mass media such as newspaper ads and posters in the public sphere were the most prominent sources for recruitment, as previous research also showed (e.g., West and Pateman, 2016). In addition to these formats, recruitment in the private sphere through friends and relatives was also successful, which extends the findings of previous research (Crall et al., 2017). Linking the project's research to people's own gardens probably facilitated recruitment, because an affective connection to participants' local environments (Dunkley, 2017) and relevance of CS to everyday life (Hart et al., 2022) have been shown to be drivers of participation. In addition, people knew that opportunities to participate were limited, and that they only had to commit for a defined amount of time (two months).

Participants' motivations clearly reflected the focus on wildlife and the desire to learn more about the animals in their own garden, while contributing to the research process was not a significant driver to participate. We are aware that the phrasing of the questions is important for assessing motivations. The link to contributing to science may have been less obvious with the question of "Why are you interested in putting up a wildlife camera in your garden?" than it may have been with a broader question such as "Why do you want to participate in the project?". However, the results regarding the answers to this question matched those regarding the applicants' interest in contributing to different steps of the research process. Furthermore, some applicants may have given socially desirable answers in order to be accepted into the project: They may have expressed their interest in analyzing data and the scientific process because we explicitly stated on the website that we expected volunteers to contribute to more than data collection. In summary, we conclude that participants were more interested in monitoring wildlife in their gardens than in contributing to science or learning about the scientific process.

Strasser et al. (2019) have stressed that the term "citizen science" itself, as well as science communication within and about CS projects influence the public perception and the expectations associated with such projects. In their communication, projects could, for example, highlight the link to the participants' everyday life, which appears to be a strong motivator in our as well as in other studies (Wagenknecht et al., 2021). In contrast, we did not find that contributing to science and learning about science were powerful recruitment messages or motivators, which is counter to a number of other studies (Raddick et al., 2010; Curtis, 2015; Land-Zandstra et al., 2015; Alender, 2016; Land-Zandstra et al., 2016; Lee et al., 2018; Lopez, 2021; Etter et al., 2023). Community building through science communication among participants as well as between participants and scientists has also been described as a success factor for CS projects (Golumbic et al., 2020). However, interaction with others in the community was not a main motivator for participants in the current study—in contrast to the online project *FoldIt* (Curtis, 2015), for example, and projects on environmental issues involving data collection in the field (Bradford and Israel, 2004; Wright et al., 2015). Of course, which factors are the main motivators for participants to contribute depends on the subject of the project, the tasks and involvement of the participants, and the personal relevance and possibilities for citizens. In our project, the link to one's own garden seems to have been the decisive factor in determining participants' motivations.

How these motivations influenced the project outcomes is elucidated by previous research in this project that investigated participants' behavioral activities on the online platform (Bruckermann et al., 2022). This study found that participants were more active and lurked less (i.e., were less passive) during the data collection phase of the project (i.e., when participants took photographs with the wildlife cameras and identified the species on the photographs). In contrast, during the data analysis phase (i.e., when participants had the opportunity to analyze their own data and the data of all participants) they were less active and lurked more. This finding corresponds to the participants' high and foremost interest in wildlife and their not so pronounced interest in data analysis or interaction with scientists. In addition, a social loafing effect, that is, a tendency to exert less effort in group activities compared to when one is acting alone (Latané et al., 1979), could also have affected participant behavior. Kaufman et al. (2016) found that in a crowdsourcing game, participants contributed less when a high number of fellow contributors was highlighted in project communication. In our case, participants may have been motivated to record the wildlife in their own garden, but felt that data analysis and discussion were covered by the professional scientists and other participants.

Applicants' motivations also show that the recruitment campaign resulted in a selection of participants who wanted to record wildlife in their gardens, and in terms of the contributions participants also acted accordingly. Their behavior corresponds to another study from our project which found no increase in participants' scientific reasoning skills in the course of the project (Bruckermann et al., 2023). This finding is in concordance with the fact that participants engaged mostly during data collection and were less active during the other steps in the research process. The motivation of participants we selected through our recruitment campaign thus may have had a significant impact on the outcomes of the project. These results emphasize that it is vital for CS projects to tailor their communication to the specific needs, interests, and motivations of the people involved. Wagenknecht et al. (2021) distinguished two objectives of communication in CS projects: 1) Communication to ensure that a project succeeds, and 2) enhancing citizens' understanding and awareness of a scientific issue. Based on the current case study, we would argue that these two objectives may confluence in cases where the success of the project depends on participants' involvement in several phases of the research process, since such involvement in turn requires an adequate understanding of this process and the scientific background.

In summary, our case study showed that science communication is highly relevant in the context of CS. On the one hand, knowledge and methods from science communication were indispensable for the recruitment of and communication with the participants: We analyzed target groups, used different marketing formats, and formulated target- and audience-oriented messages during the recruitment process as well as during the course of the project. On the other hand, our CS project was also intended as a tool for science communication in order to give participants information about urban wildlife as well as insights into and an understanding of different steps of the scientific research process. Such synergies of CS and science communication should be explicitly taken into account and further developed in the future.

# 5 Conclusion

In this case study, we highlighted the importance of purposely designing recruitment messages and strategies for CS projects. These strategies can influence the selection of participants, which in turn is an important factor for volunteer engagement and sustained contribution to the project. Our results demonstrated that, before the start of the project, researchers should deliberately consider i) which candidates are particularly suitable with regard to the project goals, ii) what are those candidates' interests and motivations, and iii) which messages and channels are needed to reach the preferred target groups. The data of this research further suggested that if CS project organizers aim at reaching a large number of potential participants, they need to use a broad range of communication formats and use them continually as long as participants need to be recruited. Finally, we could illustrate that assessing participants interests can provide helpful information that may be already relevant when starting the project. All in all, this case study presents valid and important results on the necessity of well-thought recruitment strategies that ultimately contribute to the success of CS projects.

# Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

# Author contributions

AS: Formal Analysis, Investigation, Methodology, Project administration, Visualization, Writing–original draft. HG: Methodology, Writing–original draft, Writing–review and editing. TB: Methodology, Writing–review and editing. JK: Conceptualization, Funding acquisition, Writing–review and editing. UH: Conceptualization, Funding acquisition, Writing–review and editing. MB: Conceptualization, Funding acquisition, Methodology, Supervision, Writing–original draft, Writing–review and editing.

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# Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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