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EDITED BY
Yaela N. Golumbic,
Tel-Aviv University, Israel

REVIEWED BY
Moritz Müller,
Museum of Natural History Berlin (MfN), Germany
Esther Marín-González,
Universidade de Lisboa, Portugal
Cristina Luís,
University of Lisbon, Portugal

*CORRESPONDENCE
Sinja Dittmann,
dittmann@leibniz-ipn.de

†These authors have contributed equally to this work and share first authorship

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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

Sinja Dittmann[1*†], Tim Kiessling[1†], Linda Mederake[2], Mandy Hinzmann[2], Doris Knoblauch[2], Marianne Böhm-Beck[1], Katrin Knickmeier[1] and Martin Thiel[3,4,5]

[1]Kiel Science Factory, Leibniz Institute for Science and Mathematics Education (IPN) and Kiel University, Kiel, Germany, [2]Ecologic Institute, Berlin, Germany, [3]Departamento de Biología Marina, Universidad Católica del Norte, Coquimbo, Chile, [4]Center for Ecology and Sustainable Management of Oceanic Islands, Facultad de Ciencias del Mar, Universidad Católica del Norte, Coquimbo, Chile, [5]Centro de Estudios Avanzados en Zonas Áridas (CEAZA), Coquimbo, Chile

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

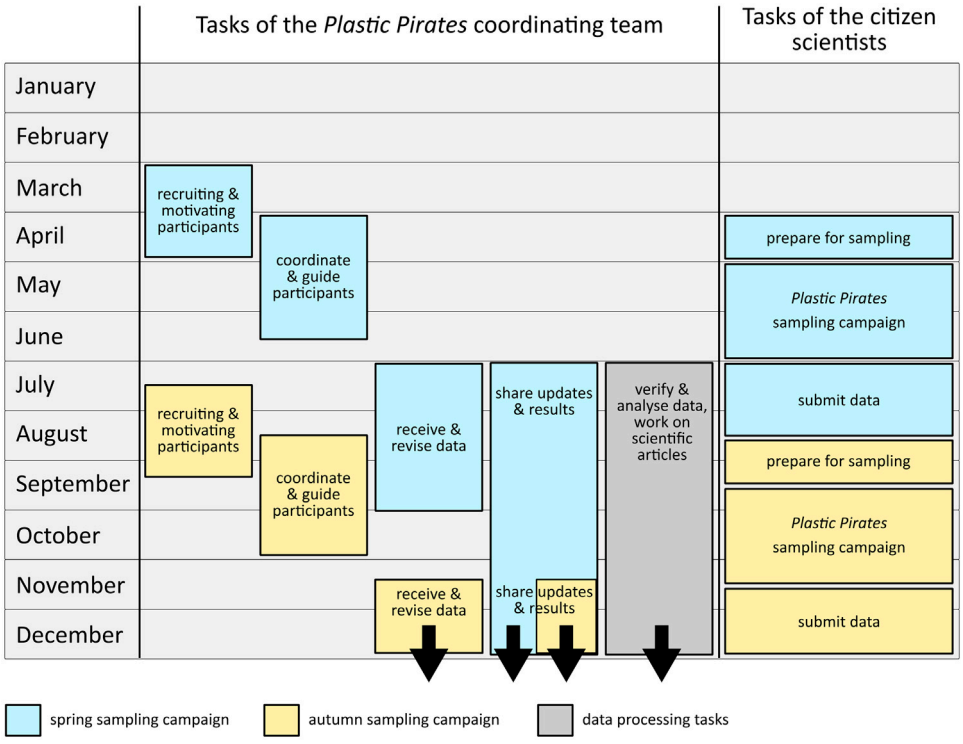

FIGURE 1
Tasks of the *Plastic Pirates* coordinating team and the citizen scientists in an exemplified year in which a spring and an autumn sampling campaign were conducted. Data processing tasks, such as citizen science data verification, data analysis and advancing work on scientific articles were 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.

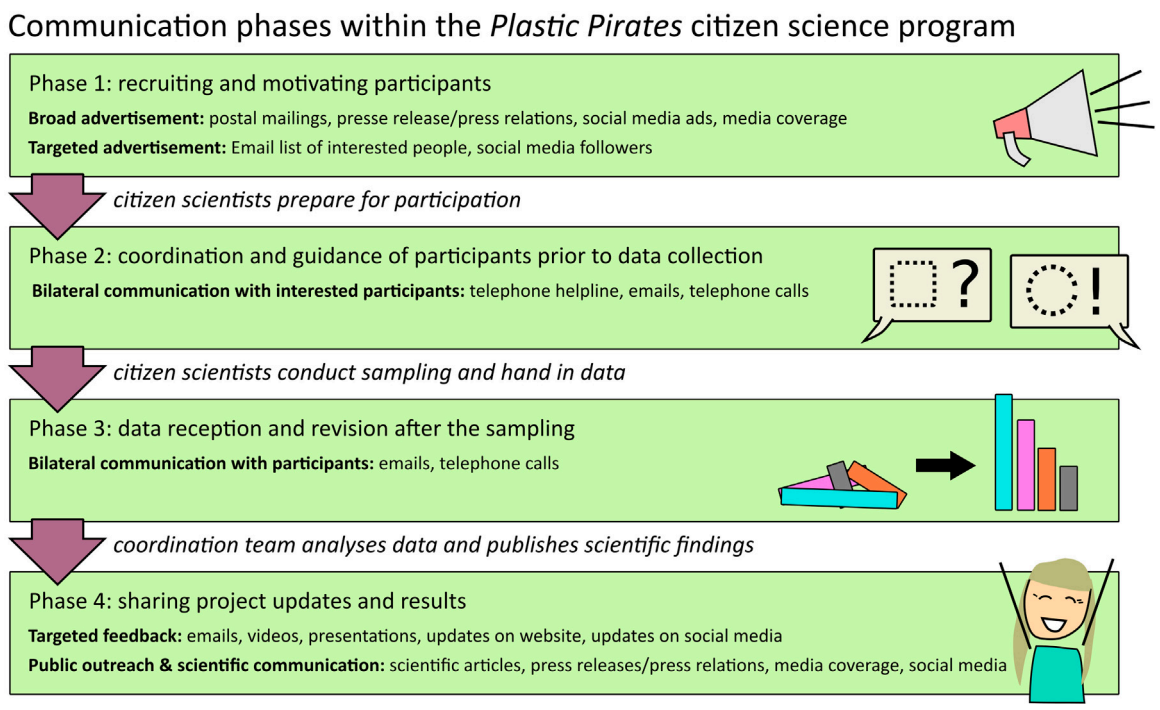

FIGURE 2
Communication tools used by the coordinating team of the citizen science program *Plastic Pirates* during the different communication phases with the participants.

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.

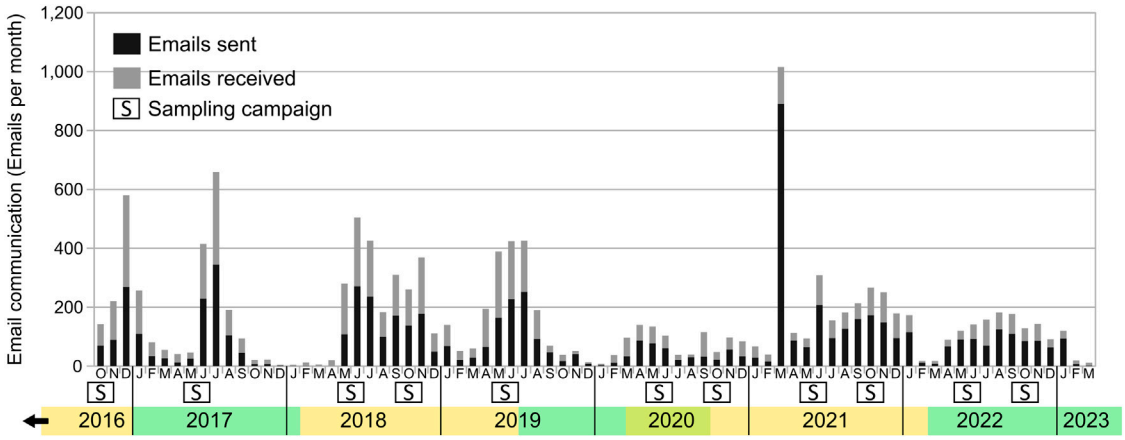

FIGURE 3
Numbers of emails sent and received per month by a centralized email address created for individual communication with participants, before, during and after the active data collection (i.e., sampling campaigns) of the *Plastic Pirates* (see Supplemental Material S1 for original data). The purpose 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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