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# Citizen Science in Practice: How (not) to Fail?

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## ABSTRACT

This article presents a collective work led by researchers and project leaders in the field of citizen science (CS). Our approach is part of the “culture of error” in CS, introduced by Westreicher et al. (2021): We share our vision of the errors and difficulties we have experienced, what we have learnt from them, and what we would do differently. This work is based on ten French projects covering a variety of goals, disciplines, and the nature of the public involved. This diversity enabled us to conduct a cross-disciplinary and free-from-specificities reflection on our practices. We have identified 3 types of errors or difficulties, which we illustrate with examples drawn from our own experience. The first type of errors is the kind we would not repeat. In contrast with these “plain” mistakes, the following two types of difficulties are an invitation to defend a more realistic vision of CS. The second type refers to the uncertainties that are inherent to the plasticity of CS projects. The third are difficulties that may lead to unexpected positive consequences, both in terms of scientific objectives and community-wise. We encourage a change in the way we look at mistakes and difficulties: Uncertainty is inherent in CS and we assert our right to experiment, make mistakes, and change practices during the life of a project.

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## INTRODUCTION

Since the mid 2000s, citizen science (CS) has expanded globally, merging different disciplines and methods of participation (Strasser et al. 2019). However, navigating CS projects, especially interactions with non-professional participants, presents complexities that are often overlooked in the existing literature, which tends to focus on theoretical aspects.

As French CS practitioners with diverse expertise in gamified platforms, environmental participation, collaborative archaeology, and more, our collective experiences reveal recurring patterns in project design, management, and outcomes. Our discussions, moreover, bring to light challenges to common assumptions about CS projects, and the fact that while some obstacles prove formidable or impossible to overcome, early mistakes are easily avoidable. This shapes our perspective within the culture of error in CS introduced by (Westreicher et al. 2021). Herein, we share our insights on identified minor errors, lessons learned from our errors and difficulties, and alternative visions. This sharing of experience and being honest about what works and what does not, will benefit other project leaders (Garcia et al. 2021).

Aimed at newcomers and current participants across disciplines and methodologies, our focus is not on providing ready-made solutions, but on highlighting pitfalls. We structure our insights around three types of common misconceptions drawn from our experiences, either because they were our own misconceptions, or because we encountered them among the other stakeholders involved in our projects. We first outline initial “plain” mistakes often made by CS project leaders due to inexperience and misjudgments in stakeholder interactions. These are mistakes that we would not make again and we detail them in the first part of this essay. In the second part, we explore the uncertainties inherent in CS projects and argue for practitioners to be aware of biases and the need for constant adaptation. Finally, we explore unexpected outcomes in CS project development, presenting deviations from the original approach as potential opportunities.

## APPROACH

Herein, we draw insights from the Science Ensemble network (<https://www.science-ensemble.org>), which comprises 53 projects from a variety of disciplines, including environmental sciences, geology, astronomy, linguistics, archaeology, history, and musicology. Most of the projects in the network work with nonprofit associations or local authorities and involve non-academic actors, making the

network a valuable sample for a comprehensive study of CS. This study is based on our experience in ten CS projects that are part of the French Science Ensemble network and led by the co-authors of this essay. Although the cases studied are unique, our aim was, through exchange during several workshops led between 2020 and 2023, to identify recurring elements through comparison, focusing on barriers specific to CS rather than project themes or disciplines.

We present in Figure 1 a synoptic table of our projects. We wish to emphasise that the number of participants is not a useful measure of success on its own. Depending on objectives and timeframe, factors such as participants’ development, diversity, retention, or contributions over time should be prioritised.

## LEARNING FROM OUR MISTAKES

### DESIGNING A CITIZEN SCIENCE PROJECT

“Simplifying the task ensures high participation”

One of the most counter-intuitive lessons we learned is that just because a project is easy to participate in does not mean that it will attract more participants. From our experience, projects that are too simple to take part in are less engaging than the more challenging ones that match the skills of the participants. This is in line with the concept of “flow,” as theorised by Nakamura and Csikszentmihalyi (2002), who studied the motivation of players and gamers. For an optimal experience, participants need to perceive a challenge that stretches their skills, and at the same time this challenge must be adapted to their skills and not seem infeasible. If the challenges exceed the skills, it creates anxiety, and if the skills exceed the challenges, it creates boredom. In the 50,000 observations for the forest project, launched in 2012, participants were asked if they had seen any typical species among 24 species such as the red squirrel (*Sciurus vulgaris*), the fire salamander (*Salamandra salamandra*) or the orange tip (*Anthocharis cardamines*) during their walks in the forest. Since it required little effort, we expected a high level of participation, which was essential for analysing this kind of imprecise data. Unfortunately, only 3,800 data points were collected during a year, which was considerable but insufficient for the scientific objectives of the project. Given the low turnout, the project was stopped after one season. Our *a posteriori* interpretation of this failure is that participation was so simple and so accessible to everyone that the potential volunteers did not feel responsible for transmitting the data. In other words, “anyone can

	Name (lifespan)	Public (region)	Contribution type	Stakeholders, Nb. participants, Nb. scientists	Data type	Objective(s)
Linguistics	<b>Recettes de Grammaire</b> (2018-2020)	Speakers of Alsatian (online)	Collection (accumulation, complementarity), analysis	- Universities, Culture Ministry - ~ 40 participants - 2 scientists	Texts, grammatical labels, spelling variants	Capture linguistic diversity and linguistic knowledge for Alsatian language
Astronomy & Geology	<b>Vigie-Ciel</b> (2015-)	General audience (mainland France, online & on-site)	Collection (acc.), analysis	- Universities, observatories, museums, scientific culture institutes (planetariums, learned societies, associations) - A few thousands participants - 10 scientists	Observation of meteors, meteorite recovery, identification of new impact craters	Involve citizens in research at the interface between astronomy and geology by identifying and describing extraterrestrial material landing on Earth
Geology	<b>Vigie-Terre</b> (2020-)	General audience (mainland France, online & on-site)	Collection (acc.)	- Universities, museums, scientific culture institutes, geoparks, nature reserve - ~ 200 participants - 3 scientists	Observation of outcrops	Report and characterise new outcrops in order to find new geological structures with scientific or heritage interest
Biodiversity & Ecology	<b>Spipoll</b> (Vigie-Nature) (2010-)	General audience (mainland France, online & on-site)	Collection (acc.), validation	- Learned societies, nature conservation associations - ~ 4,500 participants - 10 scientists	Pictures, species names	Better understand how pollinating and/or flower-visiting insect groups interact with flowers
	<b>Opération papillon</b> (Vigie-Nature) (2006-)	General audience (mainland France, on-site)	Collection (acc.)	- Environmental awareness and protection association - ~ 12,000 participants - 5 scientists	Observation of species, gardening practices	Improve scientific knowledge on butterflies. The data collected over the long term should help measure the effects of human activities on these species
	<b>Vigie-Nature Ecole</b> (2012-)	Teachers and their pupils (mainland France, on-site)	Collection (acc., comp.), analysis	- Ministry of Education, museums, associations (biodiversity preservation), towns, etc. - ~ 3,130 classes - 1 scientist	Observation of species	Monitor “common” biodiversity by implementing scientific protocols with their pupils
	<b>Suivi vers de terre OAB</b> (2010-)	Farmers (mainland France, on-site)	Collection (acc.)	- Ministry of Agriculture, chambers of agriculture, agricultural education, hunting federations, associations (farmers’ unions, naturalists), etc. - ~ 1,900 farms - 1 scientist	Observation of species, agricultural practices	Develop indicators to monitor biodiversity in agricultural environments and raise biodiversity awareness among agricultural professionals
	<b>50 000 observations pour la forêt</b> (2012-2013)	General audience (mainland France, on-site)	Collection (acc.)	- Environmental awareness and protection association - A few hundreds participants - 1 scientist	Observation of species	Monitor common forest species.
Archeology	<b>HOH</b> (2018-)	Students, local communities (Sangiran and Bumiayu, Central Java, Indonesia, on-site)	Research and protocol design, collection (acc., comp.), analysis, dissemination	- Universities, local governments, local and national cultural public institutions, local communities, traditional and administrative chiefs of villages - ~ 40 participants / year - 15 to 20 scientists	Observations, interviews, archaeological experimentation	Bring students and members of the local communities in Indonesia to work together on archaeological, prehistorical and cultural heritage conservation
Environment	<b>Lichens GO</b> (2017- )	General audience, naturalists (mainland France, Belgium, on-site)	Protocol design, participation tools co-design, collection (acc.)	- Universities, associations (naturalists, nature education), city councils - ~ 200 participants - 7 scientists	Observation of lichens species	Use lichens as bioindicators of air quality in cities in France and Belgium.

**Figure 1** Synoptic table of the projects developed by the authors.

contribute this data, there's no point in me doing it." In another project, a garden butterfly programme, volunteers feel responsible for passing on data about their garden because no one else can know what species of butterfly are in their own garden. Understanding the benefits of their personal involvement increases volunteers' motivation to get involved (Fritz et al. 2022). Similarly, when we launched Lichens GO, which invites city dwellers to observe lichens for the purpose of bio-indicating air quality, we wanted to simplify the involvement of volunteers by not asking them to identify lichen species. As recognising lichen species is considered difficult, we suggested that volunteers simply count the different species they observed and describe them. However, they often observed the same species and began to get frustrated at not being able to name them. In response to this desire to find out more about lichens, we developed a dedicated determination key, a device that helps to find the name of the species to which the observed lichen belongs. This tool is very popular and makes it much easier for volunteers to get involved in the program.

To sum up, simplicity is not the key to ensure high participation. Volunteers need to be sure that their own participation is relevant and that they are gaining something through this participation, for example, new skills or knowledge.

"Investing in error control ensures quality data."

When it comes to involving non-professionals in science, one of the recurring questions is the quality of the collected data, especially as some scientists are sceptical about the ability of lay participants to produce quality data (Kosmala et al. 2016). However, a growing number of publications show that CS projects produce high-quality data that rivals that collected by professionals (Elbroch et al. 2011; Millour and Fort 2018). In the projects carried out by the authors of this article, an effort was made in the design of the protocols to limit errors by volunteers upstream of data collection. Furthermore, examples of false data knowingly entered by participants are extremely rare. Conversely, inquiries carried out among participants in Vigie-Nature biodiversity monitoring projects show that many participants censor themselves and refrain from sending in data for fear of having made a mistake (Prevot et al. 2016). The same observation was made among the volunteers in Lichens GO, several of whom told the project leader that they preferred not to transmit data when they were not sure of themselves. This behaviour presents a risk for the project and is potentially harmful. For projects where the data can be consulted and commented on by everyone, a learning community of volunteers (Bedessem et al. 2022) is created by imitation, ensuring data quality control while potentially

reassuring the volunteers. To conclude, we found that instead of investing time in designing hidden mechanisms to prevent cheating, one might rather benefit from an open communication regarding the inherent (and accepted) risk of error and the methods used to mitigate and avoid them. Such disclosure may indeed reassure participants and discourage self-censorship.

## DEALING WITH STAKEHOLDERS

This section tackles misconceptions about who's involved in CS projects. It emphasizes that researchers need different kinds of partners to succeed, as opposed to working alone.

"A citizen science project boils down to the interaction between researchers and volunteers."

The oversimplified view of CS projects as interactions between a researcher setting tasks and volunteers performing them carries risks. In reality, interactions involve a complex network of researchers, coordinators, partner organisations, funding bodies, institutions, and participants. Co-design of projects between different stakeholders avoids duplication, takes into account different expectations, and adapts participation methods to the preferences of potential volunteers. Working with existing networks facilitates the recruitment of volunteers and aligns projects with community practices. Collaboration extends beyond NGOs to include communities, funding agencies, and institutions. Recognising the need for ongoing partnership throughout the life of the project is crucial. It should be noted that many of us have experienced in various projects that our institutions or funders do not always understand the crucial role of non-academic partners in CS projects.

Furthermore, avoiding the assumption that a single coordinator can handle all the tasks helps to prevent burnout or unsatisfactory results. Hiring skilled individuals for specific tasks such as communication, community management, and web design is beneficial, when possible. In the early stages, however, coordinators often juggle multiple tasks, which highlights the importance of training beyond traditional research activities.

"Sharing the same objectives as the stakeholders is a necessary and sufficient condition for fruitful collaboration."

Intuitively, one might think that sharing the same objectives with all the stakeholders involved is a necessary condition to engage collaboration. The experience of the Vigie-Nature project shows, on the contrary, that various objectives are pursued by different stakeholders, in line with their field of action. The researchers involved put

forward the objective of collecting standardised data, and some NGO partners give priority to raising awareness and environmental education, while the teachers mobilising their classes do so in order to adopt original teaching approaches. Over and above the objectives they prioritise, these stakeholders work together with the same ultimate concern: biodiversity preservation. The objectives that co-exist in Vigie-Nature are not contradictory, but converge towards a common goal by contributing to it in different ways (Conversy et al. 2019). What is more, the interests and objectives of the stakeholders may (i) evolve over time, and (ii) not be in line at each step of a CS program. Co-designed projects illustrate this. Co-designing with partners is useful in ensuring that the objectives of the various partners are recognised and taken into account, and it allows for a more appropriate mode of participation.

Conversely, a person sharing an interest in the topic or objectives of a project is not necessarily a good partner or participant. In the case of Recettes de Grammaire, a project in which we collected linguistic data from Alsatian speakers, our stakeholders included the local institution for the defence of Alsatian and linguists. Although they undoubtedly share our objectives of promoting and defending the presence of the Alsatian language online, no fruitful collaboration emerged with any of these potential partners. To our surprise, the local institution failed at publicising the project, and the linguists were more inclined to use the project to defend their vision of language than to contribute to it. In contrast, the most efficient communication was made through a local traditional seamstress, who had a large audience on Facebook, and the most active contributors were self-taught language enthusiasts, not professional linguists.

Our recommendation here is to take time to explore and build partnerships to better understand and take into account the objectives of all the stakeholders involved and confirm that they are compatible with project success.

## BUILDING ON UNCERTAINTY AND PRECONCEPTIONS

Here, we explore the difficulties we faced and will probably face again because they are inherent to CS. CS projects are based on pre-conceptions: Starting a project is inevitably making assumptions about the nature and motivation of participation. These preconceptions, combined with the long-term dimension of CS projects, lead us to describe how embracing plasticity is a key element in such projects. This leads us to question the image of CS, both our own and that of all the stakeholders involved.

## TIME IN CITIZEN SCIENCE

“The implementation of a CS project can be done on the same time scale as an academic research project.”

Setting up a CS project involves several steps, which vary depending on the objectives. Mobilising volunteers is a crucial stage that requires effective communication to generate interest. This process often involves trial and error, and time-consuming adjustments. Participation tools also require constant refinement; initial versions often need revision or new features. Creating an active volunteer community with optimal tools in a short period of time is almost impossible. Rather than feeling discouraged by this lengthy process, it is more constructive to see it as a natural part of long-term project success. Working with volunteers to improve participation tools ensures their adaptation and strengthens long-term engagement.

One noteworthy method is co-designing projects with volunteers, involving them in various stages. This principle is championed in the literature (Strasser et al. 2019), and the principles of the European Citizen Science Association (Robinson et al. 2018). Lichens GO exemplifies how volunteers collaborated in designing the observation protocol in 2017 (Abensour et al. 2020). However, although co-design can enhance a project, it is not universally effective. In the case of Lichens GO, co-design resulted in a specialized determination key acclaimed for its high quality, but none of the volunteers involved in the co-design of Lichens GO in 2017 are still participating today, despite our misbelief that co-design always ensures the unfailing retention of volunteers. This is in line with the fact that there is no single motivation for participation and no single profile of participants (Lotfian et al. 2020). Some are interested in building projects, others want to be in the field, still others prefer to focus on community exchanges, and so on.

These potential mismatches in timeframe, experienced almost systematically in our projects, must be kept in mind by future project leaders.

“The question of tool obsolescence will be resolved as the project progresses.”

The obsolescence of data collection tools or analysis methods is not specific to CS. However, the particularity of these projects involving citizens is that they are based on a fragile dynamic which, if it is stopped, can be very difficult to resume. It is therefore necessary to anticipate these situations. This obsolescence is well known for digital tools. Anticipating it means not only setting aside a budget

for the maintenance of tools, but also seeking new ones to update those that can no longer be maintained, while ensuring that the new versions are compatible with the old ones. The example of the garden butterfly observatory (part of Vigie-Nature) illustrates the challenges associated with digital tools. This programme, launched in 2006, invites gardeners to count the butterflies in their gardens. In 2014, the website encountered security problems and had to be closed without notice by the Museum's IT department. A new, less user-friendly site was developed as a matter of urgency, which did not include the history of volunteer participation. While the number of participants had been between 2,000 and 3,500 a year since 2006, it plummeted to 700 in 2014 and has never risen above 1,000 since (with the exception of 2020, when garden participation was particularly high due to the COVID-19 lockdown), and all this in spite of a strengthened animation and new IT tools. Obsolescence also affects non-digital tools. In the case of the implementation of a standardised data collection protocol requiring an object that volunteers should buy, the marketing discontinuation of this particular object undermines the continuity of the time series of data collected. For instance, a French earthworm observatory (part of Vigie-Nature Ecole and OAB) proposed to use a specific brand of mustard to carry out an inventory of earthworms and faced the problem that the brand in question changed its recipe. The observatory ran into difficulties again when France ran out of mustard in the autumn of 2022, leading to its suspension.

Here, again project leaders should keep in mind, and be prepared as far as possible to face obsolescence.

### PLASTICITY IN CITIZEN SCIENCE

Here, we consider the misconception, "The initial state of a project defines its position in the typology for the entire life of the project," to explore how plasticity should be considered as a fundamental characteristic of CS projects.

When initiating a CS project, it is essential to establish assumptions regarding partners, audience, protocols, and objectives. However, these are subject to fluctuations that may occur due to varying stakeholder commitments and evolving project dynamics involving researcher movements, funding alterations, or shifting volunteer priorities, which can impact commitment levels or lead to disengagement.

Acknowledging evolving stakeholder commitments by embracing a flexible project design is crucial. In 2017, the Lichens GO programme was initiated, and two years later Tela Botanica, a network of French-speaking amateur botanists, became a partner in the project, with significant benefits. The network took on the responsibility of creating a new data entry interface and a digital tool to motivate

the volunteer community. By adopting inflexible project perspectives, one may overlook promising openings and beneficial potential partnerships. Effective promotion of the projects means being able to first make assumptions about the community and then to quickly adapt to its transformations. Using a trial-and-error approach during a project's early stages helps to identify efficient methods, promoting interaction within the community. Furthermore, as already illustrated with Lichens GO project, open communication about the difficulties encountered and the evolving nature of the tools encourages ongoing volunteer input, which promotes improvement throughout the lifetime of the project.

Our recommendation here is to consider a participatory science project as an object that is always on the move and that must adapt to changing circumstances.

### (CITIZEN) SCIENCE PERCEPTION

It's a mistake to think that CS is properly understood by all the actors involved: One common preconception is that CS exists only to make up for a lack of available experts and proper funding to conduct "traditional" research.

"Citizen science is science where experts are replaced by citizens."

Beliefs commonly held about CS are that the participant community is a substitute for experts and that its main purpose is to accumulate data. This is sometimes true (e.g., [Moreschi et al. 2020](#)), but at other times, the collective knowledge of participants is more than the sum of its parts, with the complementary knowledge of a variety of individuals exceeding that of any individual expert.

Accumulating data and collecting complementary data require different project strategies, from design to evaluation. Scepticism about data quality arises from this preconception among external observers and even participants themselves. The dissonance between participants' views of science and their perceived capacity to engage constitutes a substantial impediment. Stressing the endorsement of authoritative institutions, like universities, can amplify their fear of making mistakes, particularly when data collection pertains to their knowledge. During our collection of linguistic data, we have observed confusion between our intended objective of gathering data that accurately represents real-life language practices, and the tendency for participants to produce "correct" data according to an unfamiliar norm for standard spelling. In this case, we chose to give a specific name to the data collection process, such as "I would have said it like this", in order to downplay the participants' perception of having to adhere to a precise standard.

Our experience has shown that the main risk in data collection is not the tendency of participants to cheat or deceive: The main challenge actually arises from their lack of confidence. So CS project leaders should reassure volunteers that they are not looking for expertise, but for the unique perspectives, knowledge, or experience that the volunteers can bring.

“Citizen science is cheap”

For a CS project to work, communication tools, participation tools, and human resources (communication, mediation, analysis of specific data for volunteer feedback) are required. All this comes at a cost.

After 10 years of existence, a programme such as Vigie-Nature École has reached a satisfactory level of operation, which requires a great deal of human resources. Four people work full time for Vigie-Nature École: a coordinator, a data-analyst, a web developer and a scientific mediator. Each year, 450 classes participate in 10 programs. These four people look for funding, design participation tools, provide training for teachers and pupils (40 per year), manage the databases, make the data available and analyse it, produce graphic presentations of the results, and ensure that they are disseminated and promoted. Funding for these four positions is around €250,000, not including the involvement of partners who pass on the programme to teachers and research teams who use the data.

## GOING BEYOND THE INITIAL DESTINATION

We have outlined challenges faced, yet uncertainties in CS also produce unexpected positive outcomes. Here we show how initial “limitations” yielded fruitful results regarding both participation and research.

### APPROPRIATION OF THE PROJECT BY THE VOLUNTEERS

We analyse here the mechanisms that have led to the creation of a community of participants in projects that did not call on existing communities. In the examples we selected, fostering new social relations between volunteers became an interesting outcome of the projects. In one case, the creation of the community resulted from the unexpected extensive use of a data validation tool; in the other case, it resulted from an unresponsive project leader, which allowed for spontaneous initiative by volunteers outside of the project. In Spipoll, a programme centered on pollinating insects (part of Vigie-Nature), the participation platform enabled volunteers to exchange information

about their photos. None of the programme’s promoters could have predicted how intense the interactions became. Volunteers interacted to help one another in the species determination, but also to comment positively on the aesthetics of the photos, or to kindly point out when a volunteer did not seem to have respected the protocol. We started witnessing a form of unexpected social control serving the programme by ensuring the quality of the data collected. These social interactions also benefited the volunteers, who got to know one another and organized trips to photograph insects outside of the national organisation of the programme. Furthermore, these interactions allowed volunteers to acquire knowledge and scientific skills (Bedessem et al. 2022). In the case of Lichens GO, no tool was designed to allow interaction between volunteers about the identification of lichens, but there was a mailing list. However, the Lichens GO coordinator sometimes failed to respond quickly enough to requests from volunteers asking for help in identifying lichens. When the coordinator explained that long response times were due to work overload, other volunteers took initiative to respond. By helping one another, they formed a learning community of volunteers. In this context of dynamic exchanges, when the team proposed a note on the data entry interface, volunteers spontaneously e-mailed constructive criticism, which helped to improve the tool. Following this fruitful experience, new tools were offered to volunteers for review, tools were gradually co-designed, and volunteers spontaneously suggested new tools to help lichen identification, some of them even becoming part of the programme management team. This high level of involvement emerged because the coordinator was transparent with the volunteers about the difficulties encountered, motivating them to take ownership of the project in order to improve it.

Since 2017, Human Origins Heritage (HOH) has been combining archaeology with a CS programme exploring the link between heritage and society (Biets 2021; Sémah 2021). The excavation site recruits and trains CS participants to archaeology and prehistoric heritage conservation, while the CS programme addresses social issues such as river management, tourism development, land use, or the relationship between the local institutions and the communities.

The Manyarejo Festival is organised primarily by local residents and the Sangiran museum staff with support from some HOH participants from the Manyarejo hamlet, which is rich in fossils. The event’s key focus areas are music, dance, prehistory and education. The objective of this initiative is to achieve a balance between heritage, culture, and tourism, and to prevent Manyarejo from becoming a tourism-centred hub like Krikilan, another Sangiran locality.

The organisers believe that the key to avoiding the loss of archaeological sites is to prevent natural or man-made erosion or looting through education and celebration. They therefore link their festival to an archaeological site, building on their social and participatory experiences in HOH. The festival aims to capitalise on the enthusiasm of the younger generation for celebration by strengthening their sense of belonging. This will serve as an important link between the audience, the organisers, and the cultural and archaeological richness of Manyarejo.

### UNEXPECTED SWING OF THE PROJECT

Sometimes new research questions emerge during CS projects through interactions with volunteers: Some of these new questions complement the original ones, causing the project to branch out, while some entirely redefine the course of the research.

#### Serendipitous use of data collection

We have already discussed the Spipoll project, in which volunteers commented on the photos of other volunteers, thereby creating a community of volunteers guaranteeing the quality of the data. After several years, these comments became new data for the programme. The resource thus spawned a whole new research project on the participants' perceptions of pollinating insects, biodiversity and science, and their evolution in time (Bedessem et al. 2022). On another note, volunteers of the garden butterfly observatory are asked to provide information on their gardening practices. The initial objective was to gain a better understanding of the impact of gardening practices on butterfly biodiversity, with the ultimate aim of protecting biodiversity by recommending changes in practices. Information was thus collected on the use of pesticides, the preservation of a fallow area, or the presence of certain plant species that are useful to butterflies. These data were collected to study the correlation between these practices and the butterfly biodiversity observed. Over the years, however, it became apparent that pesticide use was declining among volunteers who had been taking part for several years. In fact, the participatory approach reached its ultimate goal by itself: Rather than being told what to do in their own garden, the volunteers, by observing nature and getting to know it better, spontaneously changed to more environment-friendly behaviour (Deguines et al. 2020).

#### Emergence of research opportunities

As we have seen, involving citizens in our research is not simply a matter of compensating for a lack of human or financial resources. In this final section, we go a step further and present an example that illustrates the richness of the participatory nature of CS. We have experienced

that confronting our practices with the public can lead us to look differently at our research object and reveal new research paths. As described above, we experienced a false start with the Recettes de Grammaires project. Our initial approach consisted of collecting texts in our target languages and having the participants annotate these texts with linguistic labels (such as finding the adjectives or verbs). The substantial linguistic variations in these languages made participation difficult. In fact, we realized that, because of their intrinsic diversity, these languages called for representative linguistic resources. In order to achieve linguistic coverage, we moved from an accumulative vision of participation to a complementary one. As we incorporated the criticisms of the participants and adapted to their abilities, rather than forcing them to comply with our workflow, we opened an unprecedented research path that inspired new methods for processing these languages.

The Vigie-Terre project, launched in 2020, invites amateur geologists to provide information on new rock outcrops that have appeared as a result of natural phenomena such as landslides or road construction. The programme offers two protocols (simple and advanced) for entering data that, once submitted, are automatically posted online to make them accessible. The goal is to identify geological structures of heritage, scientific, or educational interest and to make geology accessible. This tool attracted the attention of a professor of geology at Cergy Paris University, who wanted to use it for a specific research project. He and his students had observed a number of old and unrecorded landslides in the Vexin region and wanted to record them in order to analyse them and characterise the underlying phenomena with the help of a scientific committee. The data entry forms on the Vigie-Terre participation website were suitable for collecting the data. Two elements were missing to make this mission possible: an extra field on the form for adding important data when studying landslides (a dip anomaly or slope measurement in the outcrop layers), and a dedicated page to communicate about this project to local residents and students, and to publish communication tools such as tutorials. Specific funding enabled these actions to be carried out, and the "opération Vexin" was born from and with Vigie-Terre.

#### Changing the rules

In this section, we illustrate important changes driven by CS. The first example illustrates intrinsic changes throughout the life of a programme, and the second describes how a CS programme can lead to extrinsic changes, potentially as far as changes in the law. In the Spipoll project's 13 years of existence, the role of its participants has evolved considerably. After nine years of existence, in response to the increasing competence of the participants (Deguines

et al. 2018), the project evolved to allow them to take part in the validation of the data collected. In addition, at the annual meetings between participants and scientists, participants discussed the results in greater depth, and questioned the scientists on their research hypothesis. This is consistent with the study on interactions between participants in this programme, showing that long-term participation is associated with the growing expression of scientific procedural skills: formulation of hypothesis and explanation, and proposition of new research questions (Bedessem et al. 2022). Finally, in 2022, the project's most active participant was officially appointed MNHN (National Museum of Natural History) scientific correspondent, a first for a citizen scientist of this research establishment. This example echoes the question of plasticity discussed above. If we follow the classifications in the literature (e.g., Haklay 2013), this project will have changed its level of participation since its creation, from only data collection (crowdsourcing) to problem definition, data collection, and analysis (extreme citizen science).

The Vigie-Ciel project invites enthusiasts and the general public to go in search of freshly-fallen meteorites spotted by cameras and eyewitnesses. Two meteorites were found in France in 2023. The first was found in Normandy by an 18-year-old student, Lois Leblanc-Rappe, during a search organised by the Vigie-Ciel team. This meteorite and several fragments found at that time are now on display in the Galerie de Minéralogie et de Géologie at the Muséum National d'Histoire Naturelle. The second meteorite fell on and damaged someone's garden table. She contacted the nearest outreach pole of the Vigie-Ciel programme, which in turn contacted meteorite scientists to analyse the stone.

The success of the project is limited by the fact that, unlike archaeological objects, there is no specific law on the ownership of meteorites in France. The largest whole fragment of the meteorite that fell in Normandy was found by an meteorite hunter from the United States who put it up for sale. The owners of the land on which several other fragments were found by the Vigie-Ciel team all agreed to donate those samples to the Muséum National d'Histoire Naturelle (MNHN). These, along with the one sold by the hunter, which was eventually bought and further donated to the MNHN by a generous patron, are currently being analyzed. However, most of the other fragments were searched for and sold without the landowner's permission and without systematic documentation. These events have stimulated discussions between the team and various ministries, as they highlight the need to amend French legislation to allow public institutions to study and conserve some of the samples, and to ensure that landowners and discoverers all benefit from discoveries in order to encourage research in the field.

These two examples show that CS leads us to shake up our initial research assumptions: roles change, and CS can induce changes in the law.

## CONCLUSION

Pooling our experiences has enabled us to identify avoidable mistakes and some shared misconceptions about CS. We do not aim to be exhaustive, yet we hope that this article will help future project owners, funders, and institutions promoting CS to avoid these misconceptions. We discuss how and why CS are not cheap projects where experts are replaced by volunteers, and how simplifying the role of volunteers does not ensure participation if they do not understand the objectives. Our experience shows the importance of taking into account several stakeholders and their diverse objectives for fruitful CS projects.

We also highlight the uncertainties inherent in CS and frame it as a science that is challenged by its participatory nature. It is unrealistic to seek eradication of uncertainty; instead, it is critical to understand its intrusion at different levels. Consequently, herein we assert our right to experiment, to make mistakes, and to change practices during the life of a project, as long as this matches high ethical standards. Following Garcia et al. (2021), our recommendations here are to invite other project owners to share their experiences of difficulties and of trial and error, so that they become a normal part of the life of a CS project. We have shown that these difficulties can provide beneficial opportunities for CS projects, which is all the more reason to value them. As such, we also recommend analysing and understanding mistakes rather than hiding them. Our final recommendation is to take time when launching a CS project to find, by trial and error, the methods that suit the volunteers and all the stakeholders, and to adjust them as the project goes along. This study emphasises that participation in CS goes beyond a mere research methodology. Given the discomfort of involving non-academics in research, we offer broader insights into the role of CS in research. It is crucial to see CS as an object of study in its own right, requiring deeper understanding and adaptable evaluation frameworks. The challenge is to create specific frameworks tailored to CS, and to avoid oversimplification as a practical solution.

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The authors have no competing interests to declare.

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Renaud Debailly: conceptualization (equal), formal analysis (equal), methodology (equal), writing – original draft (equal), writing – review and editing (supporting).


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