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RESEARCH ARTICLE



Online data sharing with virtual social interactions favor scientific and educational successes in a biodiversity citizen science project

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ABSTRACT

Given the diversity of biodiversity citizen science projects' design and objectives, a major challenge is to better understand the factors influencing their successes. We study an online communication space where participants to a participative biodiversity monitoring program share their data and freely interact. A quantitative analysis of the comments' distribution among participants reveals the multiplicity of epistemic and social roles they endorse: helping collective identification of plants and insects, moderating the respect of the scientific protocol, or maintaining community's life. By building a typology of these comments, we show how this space of discussion favors exchanges and reflections about esthetical, interpersonal, biological and methodological aspects. We argue that the existence of such spaces favors all together the production of high-quality data, science learning, and individual commitment towards environmental issues. Maybe more importantly, they allow citizens to build and strengthen collective epistemic and affective relationships with science.

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Introduction

Public engagement in conservation efforts is now considered desirable by many conservation professionals (Roger, Turak, and Tegar 2019) and agencies dedicated to biodiversity monitoring (IPBES 2019). Among others, citizen science (CS) programs constitute one of the forms taken by this public engagement. They include a large variety of practices where non-professional scientists participate in scientific research (Strasser et al. 2019; Eitzel et al. 2017). Three main types of citizen science projects have been described:

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(i) contributory projects where members of the public primarily collect data, (ii) collaborative projects where the public is involved not only in data collection but also in other aspects of the scientific process such as developing research goals or questions, analyzing data or disseminating findings, and (iii) co-created projects, which are co-designed by both scientist and members of the public (Bonney et al. 2009).

CS programs have become an important research tool for the environmental sciences, and they have grown in popularity for several reasons (Turrini et al. 2018). First, citizen science makes possible the collection of large data sets, which allow a long-term monitoring of organisms, populations and abiotic factors (Danielson et al. 2014; Dickinson et al. 2012). Second, CS allows the access to locations that professional scientists may be unable to access themselves (Cooper et al. 2007; Danielson et al. 2014). Third, it constitutes a cost-effective method for expensive expert-driven data collection (Levrel et al. 2010). Fourth, it might increase personal engagement towards biodiversity conservation (Cosquer, Raymond, and Prevot-Julliard 2012; Deguines et al. 2020; Haywood, Parrish, and Dolliver 2016; Johnson et al. 2014; McKinley et al. 2017). Finally, CS could increase participants' scientific knowledge about biodiversity, and public understanding of the research process (Peter, Diekötter, and Kremer 2019a; Deguines et al. 2018; Jordan et al. 2011). Regarding this last issue, the results reported in literature are quite contrasted. For instance, Evans et al. (2005) and Brossard, Lewenstein, and Bonney (2005) showed, respectively, that participants to the 'Neighborhood nestwatch' and 'The Birdhouse Network' improve their knowledge of bird biology. Similarly, Deguines et al. (2018) revealed that participants to the French 'photographic Survey of Flower Visitors' improve their insect identification skills following their participation in the program. However, mixed results were found regarding learning of scientific thinking, methods and processes. Some authors show that participation promotes the acquisition of scientific 'habits of thought' (Trumbull et al. 2000, 265; see also Evans et al. 2005; Price and Lee 2013). For instance, Evans et al. (2005) show that some participants to the 'Neighborhood nestwatch' question the research protocol as well as the quality and the quantity of the data they provide. Some participants also provide non-requested ecological and environmental information, notably by 'noting predation and nesting activities that occurred throughout their backyards' (591). Similar results were found by Trumbull et al. (2000) in the case of the 'Seed Preference Test' CS project. The author suggests that 'participation provided a forum in which participants engaged in these [scientific] habits of thoughts' (p.265). Conversely, Brossard, Lewenstein, and Bonney (2005) and Jordan, Ballard, and Phillips (2012) did not find a statistically significant effect of public engagement on participants' understanding of the scientific process. Interestingly, it seems that citizen scientists' knowledge is favored when they interact with research staff and other participants either by email, over the phone, by face-to-face meetings (Evans et al. 2005) or even via online venue to share and discuss observations (Deguines et al. 2018). If we rely on these studies, physical or online spaces dedicated to communication among participants, and between participants and scientists, might be a factor of success for the science learning objective of CS projects. These learning impact of social interactions within CS projects have been confirmed by Luczak-Rösch et al. (2014) which have analyzed online microblogging discussions linked to 10 CS projects in astronomy

from the Zooniverse citizen science platform. Still in astronomy, Jennett et al. (2016) reported the case of the discovery of a new category of galaxy made in 2008 by participants from the ‘Galaxie Zoo’ project; in this case, it seems that the existence of ‘a forum to comment and discuss ideas was crucial in enabling this discovery to take place’ (5). In other words, allowing the participants to freely interact during a citizen science project might have genuine epistemic virtues.

All these often-cited reasons of supporting biodiversity citizen science (in a nutshell: citizens learn about science while providing data to scientists) are certainly valuable. However, a condition of success of (biodiversity) citizen science programs is their ability not only to promote science learning and to collect high-quality data, but also to empower citizens by supporting the constitution of lay-expert communities having a thicker (including affective) relationships with science and the scientists (Strasser et al. 2019). In this frame, it is crucial to investigate how citizen scientists may exceed their role of individual data collector to constitute genuine communities of inquirers. Based on a case study of a French CS program, the Photographic Survey of Flower Visitors (Spipoll), the present paper determines how the use participants make of an open online space, where participants to this program share their data and freely exchange comments about any topic without external control or guidance, may promote learning of science and science processes, secure the production of a large amount of high-quality data in a large spatial and temporal extent, and develop individual commitment towards environmental issues.

Methods

Photographic survey of flower visitors

The Spipoll program (www.spipoll.org) was created in 2010 by the French Museum of Natural History (MNHN) and a French entomological learned society (OPIE for *Office Pour les Insectes et leur Environnement*). It was designed to answer scientific questions while helping volunteers learn about insects, plants, the pollination interaction that link them and the process of science. Wherever in France, participants follow a standardized protocol which is adapted to people without any prior naturalist knowledge. This protocol is as follows. First, participants pick a flowering plant of their choice and take two pictures: one of the flower and one of the close environment. Then, they take pictures of every insect visiting the flower during a 20 mins’ period. Second, they identify insects’ and plants using a dedicated online identification tool. Third, they upload their pictures and associated identifications, as well as date, time, location of observations on the Spipoll’s website, thereby making them accessible to all. Hereafter, each contribution of a participant (i.e. the pictures of a plant and its visiting insects) is termed a ‘collection’. From the beginning of the program, anyone registered on the Spipoll platform (volunteers and experts) was able to comment each other’s collections. The online platform was designed to allow the visualization of the data collected, i.e. pictures of plants and their visiting insects, by anyone, and the possibility to comment these observations was implemented without specific goal in mind but rather because such functionality was classical for website designers, however the community manager of the program used this

functionality to communicate with participants, mostly about insects' identifications and to remind the protocol when necessary. Till 2019, volunteers' insects and plants identifications were validated by experts from the OPIE and the MNHN. After this date, a participative validation was made possible: participants can now modify their identification according to other participants' comments. By 2021, more than 470 000 insect pictures were collected by 2484 participants, most of them without entomological or biological knowledge as they have declared during their inscription to the program. Spipoll's database is available at no charge to anyone, amateur or professional for any noncommercial use. It is used by researchers to study various aspects of the pollinating fauna in France (Deguines et al. 2012; Desaegher et al. 2018; Le Féon et al. 2018; Levé, Baudry, and Bessa-Gomes 2019). These scientific studies are popularized *via* participants' meetings (three meetings have been organized – two in face-to-face format and one in virtual format because of the COVID sanitary context – since 2013), traditional media such as newspapers, magazines, and radio as well as in a Facebook page and in a newsletter presenting the program's news such as meetings, insects' information, etc. The Facebook page is managed by the community manager of the program and the newsletter are managed by a communication expert (since 2013).

Research design

Given the exploratory nature of this study, we chose a research design that combines qualitative and quantitative analytical approaches to study online comments posted on the Spipoll's platform from 2010 to 2018. This empirical material represents a total of 78,500 comments (Spipoll – Vigie Nature 2010-2018). To better understand the structure of this sample, we first investigate whether all participants posted comments and whether the amount of comments posted was related to the amount of plant-pollinator data collected. To do so, we looked at the distribution of the number of comments posted per participants and relate it to the number of data sampling performed by those participants. Second, we performed a qualitative analysis of the comments' content for 10% of the comments (7850). We selected a stratified sample of comments by extracting randomly 10% of the comments from each year and each participant. This method insures the representativeness of our qualitative analysis.

Then, we descriptively coded the content of each comment included in the sample, in several cycles following Saldaña (2009). This iterative process allowed us to describe 10 comments categories within our comments' corpus. Some comments included a multiplicity of contents; in those cases, the comments were decomposed in several parts, each part being classified in the appropriate category. Categories of comments were analyzed in order to understand how participants' online interactions contribute to achieve CS objectives. Finally, to explore potential roles of participants from the kind of contents they post, we investigated whether the frequency of the different content categories differed among participant. To do so, we performed a Chi-square test on the number of comments per content category among the participant included in the dataset. We then looked for the participants whose comments' contents were significantly deviating from expectation by selecting participants having at least one standardized residual superior to 2 or inferior to -2. Such values indicate that content categories are over or under-represented in its comments, respectively. It is important to note that participants'

agreed researchers to use information entered to Spipoll platform, and that all data exported from the platform was anonymized in order to respect the French law on data privacy.

Results

Volunteers' contributions to Spipoll program

During the study period, 36,686 plant-pollinator collections were realized by 1575 volunteers. Unexpectedly over the same period, 78,500 comments were posted on the web pages presenting these collections. The contribution among the participants was strongly uneven, with most volunteers realizing few collections and posting few comments, but some others contributing massively. The relationship between the number of collections and the number of comments per participant indicates that while most volunteers realized more collections than they posted comments, those that realized the most collections posted a relatively higher number of comments (Figure 1).

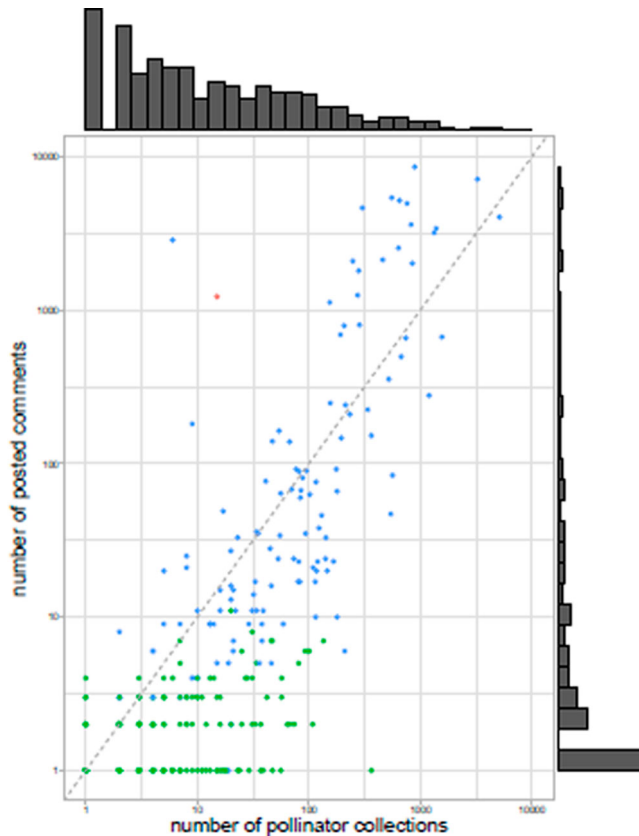


Figure 1. Relationship between the number of collections and the number of comments per participant. Each dot represents a volunteer. Blue and green dots represent the volunteers whose comments were used or not for the content analysis, respectively. Red dot represents the community manager of the program. Dot above the dashed line posted more comments than the number of collection they realized.

Comments typology: illustrating the richness of volunteers online exchanges

Our prior hypothesis was that participants mostly exchange about insect identification issues. Our content analysis show that such comments actually represent only 20.7% of the comments. As shown in Table 1, a substantial part of the comments comprises admiration comments (e.g. concerning esthetical aspects, 36.4% of the comments), reflections about biology and ecology (17% of the comments), friendly exchanges (e.g. jokes or puns, 16.7%). A part of the comments focuses on the program practice (e.g. exchanges about the protocol difficulties or thoughts concerning the program, 5%). Some exchanges concern different types of resources (e.g. bibliography or internet sites, 1.5%), and 1.3% of the comments are constituted by calls to respect the protocol. 0.6% of the comments are declarations of handling errors when downloading the information in the platform. 0.3% of the comments are notifications concerning platform incidents. 0.6% of the comments were not exploited in our study (e.g. emoticons). We describe more in details each of these categories in the following.

Showing admiration

A majority of comments (36.4%) express admiration to the observed plant or animal: *Incredible animal!!*; to the environment: *What a lovely garden!*; to the collection itself: *Beautiful collection! Very varied!*; or to the photo: *Amazing photo, well done!*. Some of them make note, when expressing admiration, of different types of difficulties faced by the participants (e.g. environmental; technical, etc.): *Beautiful pictures despite the wind, well done*. The last three examples also suggest an admiration towards the person realizing the collections. Some comments show more explicitly this type of admiration towards individuals: *Awesome! We see that you have an experience in making pictures and in performing insects' identification*.

Exchanging about insects' and plants' identification

As expected, a substantial part of the comments (20.7%) focus on topics linked to observed plants' and insects' identification. Some of these comments highlight difficulties or doubts in identifying some specimens: *I am not sure about the butterfly*. Another part of them are constituted by information which are shared by individuals to guide the identification: *The last one is a male Halicte. It is recognizable by its long antennae and its thin and elongated abdomen. But, in the next collection, the one that you have identified as an hymenoptera is not a male (shorter antennae)*. There are also collective discussions which aim at cooperatively identifying a specimen: *I agree with X about the céphale in number four, the fly in number nine maybe a tachinaire fauve*. Also, we found comments

Table 1. Main categories of comments, and corresponding sample sizes.

Category of comment	Sample size (and % of the total sample)
Admiration comments	3268 (33.9%)
Identification of species	1965 (20.4%)
Friendly conversations	1784 (18.5%)
Biology and ecology related comments	1640 (17%)
Comments about the Spipoll practices	501 (5.2%)
References to external resources	154 (1.6%)
Calls to respect the protocol	126 (1.3%)

which show how the observation of other participants' collections contribute to the updating of one's identifications: *I found many times the same butterfly as you, the red one, and I identified it as a micro-lepidotera, because of its size. What do the specialists think?.*

Exchanging about biological topics

This category of comments represents 17% of the studied corpus. It contains exchanges about different natural processes, at different levels. For instance, at species level, we found comments highlighting insects' behavior: *Note that the drone is incapable of feeding itself, it is maintained with porridge by its sisters in the hive* or about plants properties: *The parsnip is an excellent root, rich in proteins, starches, and pectins. It contains 30 mg/100 g of C vitamin.* This category also includes exchanges regarding species frequency or rarity: *unusual and interesting species.* Besides, we observed exchanges highlighting or interrogating the particularities of insects-plants interactions: *I am amazed to see all these collections which are realized on highly visited wild carrots. At home I have many of those, which I never cut, but I only saw mordelles and a few waves of little gnates while other plants attract so many butterflies and a variety of insects. What could be the reason?; [...] since a while I found lots of little snails nestled in the heart of several flowers. What are they looking for over there?.* These exchanges about plants-insects interactions often focus on plants' relative attractiveness towards the insects: *I did not know these smalls flowers, they seem to attract insects a lot!; [...] It seemed to me that forsythias didn't attract pollinators, and yet! even plants with a bad reputation do it!.* Some comments point out to the environmental conditions: (talking about domestic bees) *[...] I am perplexed by their release in this fairly cool temperature 15-17 degrees, a little bit more under the sun, of course ... Some small valleys that they fly over are still frozen around noon (12 h).* Furthermore, a certain amount of comments express different forms of scientific reasoning: formulation of hypothesis: *I guess this is due to the warm weather, the bees from the nests nearby have not been killed by cold*); result obtained from an inductive process: *It's funny: from my almost hundred observations from 2005, these ones love Teasels, lavender and Hollyhock*; suggestion of research questions: *May we measure global warming with the insects collected at this period?*; identification of new, unexpected observations: *This collection is extraordinary: it shows an unknown species*

Friendly exchanges

16.7% of the studied comments show that the Spipoll online space of communication is considered by the participants as a friendly environment of discussion. Comments in this category express kind remarks: *Thanks X for the visit*; warm welcomes to new volunteers: *[...] Welcome to the spipolliens house* or friendly remarks concerning Spipoll practice: *Did you enjoy the perfume of this beauty who bears her name very well?.* Some of the comments in this category seems to highlight friendly ties developed online: *I dedicate this collection to X and X [...],* with occurrences of jokes: *[...] all these butterflies at your home! Spipoll meeting in Ardèche! Spipoll meeting in Ardèche! Spipoll meeting in Ardèche!* or invitations to practice Spipoll together: *Thank you for your varied and unexpected comments. You have started your France tour, let me know when you will be in the south; we will organize a special spipollian party. Beautiful roses in Paris.*

Exchanging about the Spipoll practice

5% of the studied corpus concern material considerations about Spipoll practices, such as the photographic equipment used: *Photos are taken with a reflex Nikon d3100, with a 1804 mm objective, but I also miss some insects* or the equipment favoring a comfortable development of the field work: *The armchair it is the best investment to practice Spipoll comfortably*. This category also includes comments expressing different types of difficulties which are encountered when applying the protocol such as: environmental difficulties during the field work: *I did not succeed in making a collection on tamaris, too much wind!*; difficulties linked to the chosen plant: *It is difficult to make photos of the raspberry bush, because the leaves are thick and they are often hidden*; data treatment difficulties: *It is not obvious to sort the flies* or difficulties related to individual constraints: *I am on late in recording collections (still some summer collections to come). Two children of 17 months and 4 years with a full-time job, it is time-consuming!*. Furthermore, some comments insist on the discoveries realized when working on the photos at home: *I discovered this small stuff when I did the sorting*. The learning and social benefits of the programs for individuals are also figured out in some comments: *Practice is essential for identification. It becomes very easy and our mistakes are corrected by the experts from OPI and by our spipollian colleagues. Thanks to all!*; *Spipoll opened my mind to a world of beauty that I had never explored. And I also found a lot of nice people*. Finally, this category includes comments providing volunteers critical remarks about the program: *It is a bit frustrating to sort flies in the 'indetermined' category, so if some of you know usual or latine names ...*

Exchanges concerning different types of resources

1.5% of the studied comments share resources such as internet sites, forums, blogs from naturalist experts: 'See <http://aramel.free.fr/INSECTES11-34.shtml>'; books: 'From Michael Chinery's book, this scorpion fly (photo number 9) would be *Panorpa meridionalis*' or even Spipoll's resources, such as the protocol: 'Look at the advices regarding Spipoll's protocol and in the forum' or the identification key: 'A precious help: consulting galleries sorted by taxon. I did myself a CD of sorted photos of taxons'. These resources also provide knowledge elements concerning biological topics: 'Extracted from http://www.developpement-durable.gouv.fr/IMG/pdf/Pollinisateurs_03-09-2012.pdf. Orchids from Orphys type developed another strategy: they do not produce nectar but every species attract the male from one bee species by imitating the form, pattern and smell (pheromones) from its female'. Finally, we identified some promotions of others participative research projects: 'Researchers from the CNRS are interested on fireflies: <http://estuaire.net/nos-projets/observatoire-des-vers-luisants>'.

Incentive to follow the protocol

This category of comments represents 1,3% of the studied corpus. These comments express volunteers' call to respect the protocol: *Do not make a session for each insect; every insect which come to this lavender should be considered in one session*.

Statements of mistakes made

0,6% of the studied comments express bad manipulations performed: *click error*.

Notifications concerning platform incidents

Volunteers also express problems affecting the use of the Spipoll platform (0.3%): ‘I have difficulties in connecting myself to the website. It is impossible for me to open the galleries and identification keys. I installed repeatedly Java, but it did not work’. This comments are linked to several bugs and crashes encountered by the Spipoll platform during the first two to three months of the program.

Volunteers roles in the program are not uniform

Comments’ contents were variable among volunteers, as shown by a Chi-square test comparing the number of comments per category, for the different contributors (Chi-square test: $\chi^2 = 3469.4$, p value $< .0001$). Looking at the volunteers whose comments’ contents deviate most from expectations, we noted that these volunteers tend to strongly specialize on one or a few types of contents (Figure 2). This result suggests that beyond producing ecological data, volunteers actually perform multiple roles in the program *via* the comment they post, such as: to help others to identify plants and insects, to moderate the respect of the protocol and to facilitate the creation and maintain the activity of volunteers’ community.

Participants as expert-citizen: helping others to identify plants and insects

Despite the fact that most of the Spipoll volunteers started their practice without previous naturalist knowledge, it seems that some volunteers occupy a place of referent in species identifications. Either they provide the correct identification: *The americian phytolacca* or they provide tips to correctly carried out this identification process: *I would have been tempted to classify the latter as a Gamma since we can clearly see the characteristic mark on the wings*.

Participants as moderators

Researchers from the MNHN and the community manager of the program used comments to remind volunteers of some aspects of the protocol. The same role seems to be performed by some volunteers. For instance, some comments point out to missing data: *The picture of the environment is missing*; to inadequate number of pictures per insect: *Welcome to Spipoll X, the protocol demands only one photo posted on the site, specifying the number of individuals observed. Best regards* or even call to work on the pictures in order to facilitate identifications: *The insects would deserve a cropping to favor their observation*.

Participants facilitating the creation and life of a volunteers’ community

Spipoll’s online platform was not explicitly thought to favor participant’s exchanges. Nevertheless, as stated before, it seems that the possibility of commenting in each other’s collections favored the emergence and activity of a ‘Spipollian community’, here understood as a collective of people having and sharing certain attitudes and interests in common (including scientific interest, but also technical, esthetics and social ones). This community cultivates an environment of respect: *Respect! The expert spoke*; kindness: *The collection is not usable for Spipoll but, don’t be discouraged, we all went through it at the beginning! Look at the advice in the Spipoll protocol and in the*

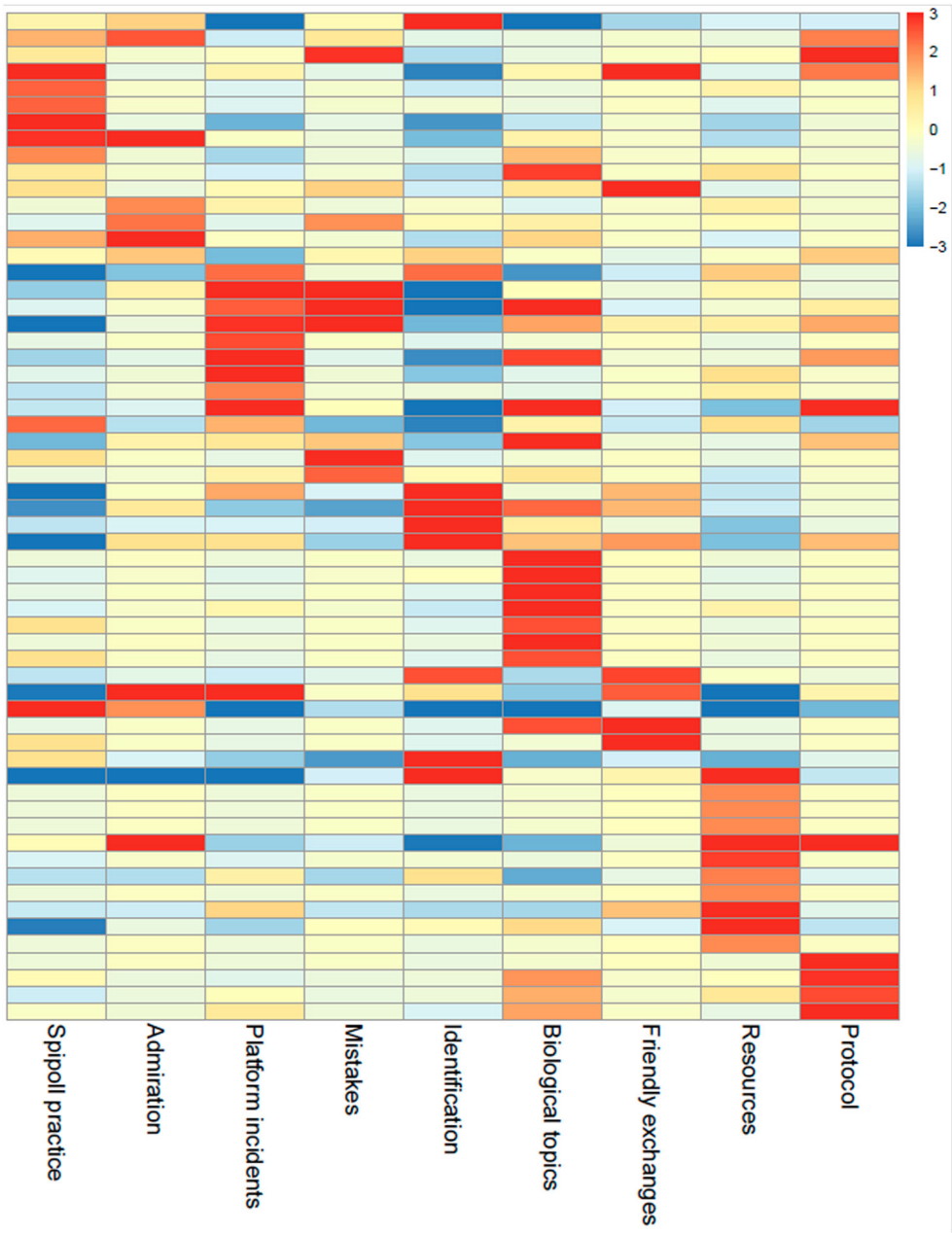


Figure 2. Over and under-representation of content categories within the comments posted by some volunteers. Each of the 60 lines represent a contributor, and each of the 9 columns represents a comment category. The color of each cell then represent the residual of the chi-square test comparing the number of comment per category, for the different contributors. A positive, or negative, residual indicates an over, or under, representation (respectively) of a given content category in the comments posted by the corresponding contributor.

forum and humor: *Apis new year* accompanying the exchanges. Our hypothesis is that some volunteers, by the comments they post, play a major role in maintaining this dynamics of exchanges. For instance, we found a participant commenting almost up to 8 times more (9048 comments) than the community manager of the program (1172 comments) during the same time-lapse (see [Figure 1](#)).

Discussion

On the basis of our analysis of the online exchanges among *Spipoll*'s participants, we defend in the following that such a free communication space contributes to achieve different types of successes of CS projects. "Success" is here defined as the realization of some of the objectives commonly associated to citizen science programs in the specific field of conservation science: promoting learning of science content and science process; securing the production of a large amount of high-quality data in a large spatial and temporal extent, and developing individual commitment towards biodiversity conservation and environment-related problems. An important point to note is that our study is limited to the formulation of hypothesis regarding the effects of participants' interactions on data quality, science learning, or long-term engagement of the participants. In the following, we then mostly explicit possible mechanisms through which these interactions might foster different kinds of successes of citizen science projects.

Learning of science content and science process

Getting knowledge or skills about natural history, biodiversity dynamics, or scientific methods and processes constitute an important objective of CS programs (Phillips et al. 2018). Deguines et al. (2018) revealed that *Spipoll* volunteers improve in correctly identifying species among the 593 non-overlapping insect taxa described in the identification-key. The authors show that the probability of correct identification did not depend on participants' self-attributed level of entomological knowledge (participants are mostly beginners), and suggest that the acquisition of knowledge is favored by the "level of social integration measured as the number of submitted and received comments per photograph shared" (203). Our comments' content analysis suggests distinct mechanisms through which the act of learning might take place. First, the exchange of information about insect species may foster individual learning by a dialectic process. On the one hand, volunteers' identification comments suggest that some volunteers develop a certain expertise for identification. Volunteers with more identification abilities share their knowledge by providing tips to correctly identify insects or plants, but also by correcting bad identifications. On the other hand, participants with less knowledge are given the possibility to demand support and tips to learn how to correctly identify insects and/or plants. By doing so, they recognize, sometimes explicitly, other participants' expertise. This dynamics may catalyze collaborative ways of learning. It is worth noting that *Spipoll* was not originally designed to explicitly grade volunteers experience (i. e. from beginners to intermediate and expert status) as other programs do to favor knowledge and skills acquisition, for instance the 'iSpot' program (Silvertown et al. 2015). However, even in this last case, the social recognition of participants' skills seems to depend primarily

on volunteers' online activity (Silvertown et al. 2015). This result is coherent with our findings that participants who realize most collections (that is, most skilled participants) post the highest number of comments (Figure 1). Second, volunteers contribute to the development and/or diffusion of knowledge concerning biological topics, such as the effect of environmental changes on plants-insects' interactions, the functions and uses of plants, or insects' behavior. As such, Spipoll does not only promote collective identification learning, but also the diffusion and discussion of knowledge about a diversity of biological topics. This dynamics is promoted by the sharing of numerous external resources. These resources might help volunteers to improve both their identification skills and their knowledge of natural history. Third, our comments' content analysis shows the emergence of a cognitive interest, from individuals, for the nature of the research procedures. This dynamics might enhance collective learning. To illustrate that point, one may refer here to the group of comments which insist on the importance of respecting Spipoll's protocol; to the group of comments which provide reflections about environmental and technical factors that may influence data collection; or to the comments which propose ways to improve Spipoll's protocol. Besides, our comments' content analysis shows that Spipoll volunteers sometimes formulate hypothesis and original questions on the basis of observed phenomena. This behavior is cogent with the fact that the Spipoll, as a monitoring program, is not hypothesis-driven. Generally speaking, participants seem to exhibit a willing to solve collectively the material, physical or intellectual difficulties or issues they encounter when applying Spipoll's protocol. To do so, they use and share their own knowledge and skills – about photographic or field work material and facilities, species' identification, insects' behavior, or general biology and environmental sciences. This result is cogent with Trumbull et al.'s (2000) study, even if the Spipoll has been designed as a contributory citizen science project, with a strict protocol which limits volunteers' scientific freedom. This strong cognitive engagement towards scientific knowledge and procedures participates in the constitution of genuine 'epistemic subjects', in the sense of Kasperowski and Hillman (2018): that is, agents which are able to follow and understand a scientific protocol, to integrate the knowledge they gain in a coherently organized way, to formulate new ideas and hypothesis, and eventually to make and recognize serendipitous discoveries.

Finally, as we express implicitly in the previous lines, one can make the hypothesis that these mechanisms of collective learning are made possible thanks to the multiplicity of roles spontaneously endorsed by the participants. For instance, participants who become experts-citizens in insects' identification, or in Spipoll's procedures, might facilitate knowledge transfer; participants who 'specialize' in animating volunteers' online community (by posting admiring or friendly comments) maintain a pleasant social environment where volunteers seem to feel free to ask questions or express about everything without being afraid of others' discredit.

Providing high-quality data in a large spatial and temporal extent

One of the main motivations for researchers or public agencies in setting up CS programs to monitor biodiversity is the ability of these programs to deliver data about biodiversity (Turrini et al. 2018). Spipoll is accessible to a diverse (urban or rural) audience, and the produced collections provide the scientists with a vast quantity of data. Spipoll program

have led to numerous scientific publications in peer-review journals, concerning for instance urbanization's effects on community composition (Deguines et al. 2016), contrasted affinities of pollinators with different land-use (Deguines et al. 2012), the role of domestic gardens as favorable pollinator habitats in impervious landscapes (Levé, Baudry, and Bessa-Gomes 2019) or floral morphology as the main driver of flower-feeding insect occurrences in the Paris region (Desaegher et al. 2018). These productions suggest that the Spipoll CS program reach the objective of collecting reliable and usable data. However, not all CS programs achieve this objective of collecting datasets that can be used in robust scientific studies (Bird et al. 2014). To be useful for science and policy action, participative production of data should go with an exigency of epistemic quality and reliability (Bedessem and Ruphy 2020). These ones mainly depend on the ability of participants to follow a specific protocol, on the quality control exerted by scientists on the produced data or results, and on the capacity of the programs to motivate and secure participation. In a study comparing the data quality of the Spipoll program and its equivalent in South Korea (K-Spipoll), Serret et al. (2019) suggest that the 'community management' of the Spipoll's social network promotes a better respect of the protocol from the participants, notably by providing online personalized and constructive feedbacks. Our results well support this last hypothesis. The different roles played by volunteers, as well as the diverse categories or posted comments, suggest indeed that virtual spaces of communication might actively contribute to the realization of these epistemic objectives of CS programs by several mechanisms. First, the exchanges of commentaries dedicated to the identification of species may contribute to the improvement of the reliability of the data provided by the participants. By sharing individual expertise about insects and flowers' identification, citizens build an epistemic community which develops a contributive way to identify species. This results might provide an explanation to Deguines et al. (2018) finding that Spipoll participants' 'level of social integration (measured as the number of submitted and received comments per photograph shared) [is] positively associated with observers' progress in accurately identifying photographed insects' (203). Second, by pointing out mistakes or bad practices appearing during the Spipoll practice, citizens exert a form of mutual epistemic control which might contribute to the collective improvement of data quality and reliability. Third, participants also share resources that act as epistemic control tools. By referring to epistemic authorities, participants exchange reliable information which guides their data collection. Fourth, the capacity of CS programs to motivate and secure participation is a well-known condition of their epistemic success, since it provides scientists with large amount of data in a large spatial and temporal extent, which is considered decisive to detect potential changes in the surveyed ecological processes and understand their underlying causes and their effects on, as well as the responses of, socio-ecosystems (Devictor, Whittaker, and Beltrame 2010). Additionally, long-term participation contributes to improve individual performance in collecting high-quality and reliable data, as shown for instance by Vallabh et al. (2016) who demonstrate that volunteers enter into a learning curve along the time of their participation. Even if we do not have information to evaluate the capacity of the Spipoll program to motivate and secure participation, we hypothesize that comments associated to friendly exchanges might play a role in it. One can indeed make the hypothesis that the constitution of a socially enjoyable zone acts as a motivator for people to engage in long-term and regular manner. This hypothesis is

supported by Kountoupes and Oberhauser (2008)'s findings about participants of the 'Monarch Larva Monitoring Project' which describe their engagement towards the program as a form of 'science bonding'. As a research perspective, this hypothesis could be reinforced by comparing Spipoll participants' engagement with participants' engagement in other programs without such communication spaces.

Developing individual commitment towards biodiversity conservation and environment-related problems

Raising participants' commitment towards biodiversity and environment-related problems is often an explicit objective, or at least a desired by-product of CS projects (Jordan et al. 2011). However, literature concerning participant outcomes of biodiversity CS projects is contrasted regarding that point (Peter, Diekötter, and Kremer 2019b). Participation has been shown to promote, in some cases, individual commitment towards pro-biodiversity practices, such as the reduction in the use of pesticides in private gardens (Deguines et al. 2020) or vote intentions towards candidates showing a desire to improve biodiversity state (Prévot et al. 2018). Other studies show little or no change in attitudes towards the environment (Brossard, Lewenstein, and Bonney 2005; Crall et al. 2013). As stated on the literature, the characteristics of one's personal relationships to the environment depends both on cognitive factors, such as the level of science literacy regarding environmental issues (Frick, Kaiser, and Wilson 2004), but also on affective ones, such as the feeling of being emotionally connected to the natural world (Tam 2013). Emotions and conviviality which raise from collective discussions or works related to biodiversity issues also influence personal commitment towards the environment (Gabillet, Arpin, and Prévot 2020). Our analyses suggest that Spipoll's virtual space of communication may promote individual commitment through these cognitive and affective factors. First, as we already noticed, this space might enhance scientific learning and the constitution of epistemic subjects; yet, these dynamics clearly points out to the cognitive factors which favor engagement towards the environment. Second, concerning the affective dimension of individual commitment, two elements should be figured out. First, the comments expressing admiration towards participants' data suggest that the sharing of pictures stimulates esthetic feelings about natural elements (e.g. flowers and insects). A hypothesis would be that these esthetics feelings enhance individual commitment towards natural environment. Various authors have indeed insisted on the fact that 'aesthetic valuing (...) underpins many of our attitudes toward the environment' (Brady 2006, 278). More precisely, it can be supposed that the esthetic valuation of the natural world participates to the 'development of an ethical attitude toward the environment', that is, an attitude which implies to treat the natural environment with respect and care (277). Second, friendly comments as well as the general benevolence of the online exchanges between participants suggest that virtual interactions enhance a form of affective attachment to the program, through the personal relationships which emerge from Spipoll practices. This social dynamics might contributes to the raise of affective links towards the environment as a shared object deserving scientific attention and collective action. Perhaps this social dynamics may be reinforced by the physical meetings, regularly organized by the project's managers, which gather the researchers and the participants. This hypothesis is guided by Gabillet, Arpin, and Prévot

(2020) findings about the way emotions, and specifically hope, drives long-term public engagement in two participative environmental monitoring programs (*Alpages Sentinelles* and *Propage*). The authors show that conviviality and social relationships among the participants are key elements to generate affective attachment to the programs as a tool to act concretely in favor of the environment. Additionally, Gabillet et al.'s study emphasizes the importance of meetings and collective events where participants realize 'that something [is] actually happening' and 'celebrate what [have] been achieved so far' (19) to favor this attachment. We then make the hypothesis that virtual spaces somehow act in the same way and vitalize participants' engagement towards the program, and participants' commitment towards environmental and conservation issues.

Conclusion

In this study, we explore participants' specific use of an online space of discussion. We deduce from these analysis some hypothesis about how this use might promote the achievement of different kinds of objectives of biodiversity citizen science: promoting science learning, providing reliable and useful data, and developing personal (cognitive and emotional) commitment towards biodiversity. Spipoll's platform, by allowing the participants to freely exchange about any subjects, give them the opportunity to exceed the mere realization of the scientific protocol and to endorse the (social or epistemic) role that best suit them: offering one's expertise in insect and flower identification, providing technical tips, sharing external knowledge resources, animating discussions, motivating others participation by commenting their pictures. Spipoll' platform constitutes an arena where a diversity of exchanges take place regardless of participants' level of naturalistic or scientific knowledge: friendly exchanges are mixed with technical concerns about data collection, with comments on insects and flowers pictures and with general considerations about ecological subjects. An important point is that this online community was built and flourished without any direct incentives or guidance from the researchers, and developed well beyond what these ones originally anticipated. Finally, our take-home message is the following: the kind of online platform which is proposed by the Spipoll program (that is, a free and open online space of data sharing and communication) promotes the constitution of a benevolent community of participants, which itself might support the realization of different kinds of objectives commonly expected from citizen science programs. In that sense, it clearly constitutes a factor of success of public engagement in science. However, out of these classical objectives devoted to citizen science, a central finding is also that Spipoll's online platform reveals and promotes more complex relationships with science and the scientists. Individuals, through the specific use they make of this data-sharing space, constitute and strengthen a genuine community of inquirers in the sense of Pier-Luigi (2018): an ensemble of individuals which, while expressing variable sets of values and affective links, share a certain 'scientific mentality' (182). The online dynamics we figured out then largely exceeds the thin perspective of a deficit model which would merely expect from public engagement an enhanced support and deference towards professional researchers. Participants, by constituting and animating this online community, develop a form of autonomous relationships to ecological and environment sciences: the community of participants becomes, to some extent, an auto-regulated space of knowledge production. Out of

these epistemic considerations, participants might also cultivate an affective link to the scientific endeavor, through the intra-community friendly interactions, and through the esthetics feelings they express and share. However, to better understand the mechanisms which underlay this social dynamics, this study should be completed by an in-depth analysis of participants' profile (e.g. social class, education level, profession) and participants' learning curve. It would also be relevant to analyze how the different roles endorsed by the participants within the program evolve (or not) over time. Out of their academic interest, we do think that these researches will reveal crucial to improve the epistemic, educational and social impacts of the biodiversity citizen science projects.

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