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Engagement and communication features of scientifically successful citizen science projects

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Abstract

The rise of citizen science in the past decade has brought many opportunities for scientists and publics alongside many challenges and questions regarding best practices. These include questions regarding, public engagement, project design and measures of success. The aim of this study is to better understand what makes citizen science projects scientifically successful, and highlight what can be learned and implemented in future project design. We focus on scientifically productive projects as a success measure that can encourage greater scientists' involvement in citizen science, and analyze five of these projects for factors that contribute to their success. We found that although all projects have strong scientific goals, they all have additional strong emphases on communication and social practices, providing a good user experience and generating motivation and empowerment. We provide five heuristics for the future design of citizen science projects which focus on engagement and communication features which we believe are important for citizen science project success.

Key words

Public engagement, Public participation in scientific research, Citizen science, design

Introduction

The rapidly growing field of citizen science involves volunteers in the active process of scientific research in collaboration with professional scientists (Bonney, Shirk, & Phillips, 2013). With both global and local foci, the scope and diversity of citizen science projects is quite wide spanning disciplines such as biology, astronomy, physics, computer science and more. However, citizen science remains most prevalent in the fields of ecology, environment and sustainability (Dickinson et al., 2012; Pocock, Tweddle, Savage, Robinson, & Roy, 2017), as participants engage in monitoring biodiversity, mapping invasive plants, reporting environmental hazards or one of many other research activities.

Depending on the type of project, volunteers can engage in processes such as data collection and data analysis, but also in defining research questions and building hypotheses (Bonney et al., 2009). For example, The NestWatch project (https://nestwatch.org) engages volunteers in collecting data on bird nest, including nesting timings, number of eggs laid, hatching, and hatchlings survival (Phillips, Bonney, & Shirk 2012). The Gardenroots (https://gardenroots.arizona.edu), a project aimed to asses contaminated soil in gardens, engages participants in all planning aspect of the research, including defining research questions, developing hypotheses (where the contamination is likely to be) and designing data collection methods (such as where to collect soil from). Volunteers further collect samples and after external analysis, take part in interpreting the data and drawing conclusions (determining whether their soil is contaminated and if there is a risk of exposure) (Ramirez-Andreotta, Brusseau, Artiola, Maier, & Gandolfi, 2015).

Although citizen science has been exponentially growing in the past decade, it is not a completely new phenomenon. Amateur scientists were involved in collecting specimens, weather observers, and recording important agronomical events (such as sowing, harvests, and pest outbreaks), for generations (Miller-Rushing, Primack, & Bonney 2012). The rise in numbers of participants in the last decade can be attributed to technological developments, especially the rise of the internet and ownership of smartphones (Bonney et al., 2014). Today, it is easier than ever to record observations, take pictures and upload information, without the need for special preparations or equipment (Dehnen-Schmutz, Foster, Owen, & Persello, 2016). Another explanation for the growth of citizen science is the mutual benefits obtained; for science and scientists and for the participating publics, as described by Bonney et al. (2014). Whether an individual volunteer, a student, teacher, scientists or government official, all participants should have something to gain (Shirk et al., 2012). Benefits for participants can include acquiring skills and knowledge, hands-on experience and understanding of scientific processes, community building and a sense of achievement and pleasure in contribution to science (Brossard, Lewenstein, & Bonney 2005; Raddick et al. 2009). Citizen science can also have important implications for society as a whole, this may include raising awareness to social and environmental issues, influencing policy makers and legislation, and developing positive attitudes and behaviors toward science (Ballard, Dixon, & Harris 2017; Forrester et al. 2017).

Citizen science incorporates many science and environmental communication practices by introducing new relevant scientific information and providing opportunities for participants to address scientific topics that are relevant to their lives (Haywood & Besley 2014; Sagy et al. 2019). Yet citizen science pushes public engagement beyond the core scientific focus to a more issue-specific practice. It creates communities of practice, empowers participants, enables them to become advocates and activists for the environment and take control over their lives (Davis, Fähnrich, Nepote, Riedlinger, & Trench, 2018).

The growth of citizen science is also illustrated by the increasing number of scientific publications based on citizen science data as demonstrated by Follett & Strezov, (2015), Kullenberg & Kasperowski, (2016) and others. These publications include scientific outcomes of citizen science projects, overviews and reviews of citizen science and articles discussing methodologies of data collection and data validation (Follett & Strezov, 2015). In 2015 alone, 402 peer review articles were published, addressing or using citizen science data (Kullenberg & Kasperowski, 2016). However, the lion share of scientific publications is nevertheless produced by a relatively small number of citizen science projects (Theobald et al., 2015). Kullenberg & Kasperowski (2016) found that only 15% of projects included in their large-scope review of citizen science (490 projects) had a scientific output in terms of publications. Similarly, Theobald et al., (2015), who reviewed 388 citizen science projects, found that only 12% produced publication in peer-reviewed journals. Overall it seems, many citizen science projects may not actually be successful in terms of their scientific productivity, as measured by publications in peer-reviewed scientific outlets.

While these projects may be extremely successful in terms of other potential goals (e.g. social, educational, engagement etc.), the limited publication rate may indicate some projects do not meet their intended scientific goals. This is an important factor to consider, since citizen science is part of science, and the core objective of science is to produce and disseminate scientific knowledge. Furthermore, Tulloch, Possingham, Joseph, Szabo, & Martin, (2013) note that the low publication rate resulting from citizen science projects may be discouraging and demotivating for many scientists. This, in turn, could weaken the support of scientists towards citizen science and hinder further development of the field.

For this reason, and in line with the existing calls to investigate what makes a "successful" citizen science project (e.g. Newman et al., 2012), we deem that it is important to carefully study those citizen science projects that excel both in public engagement and scientific productivity. Examining such projects may provide a better understanding of project design and provide guidelines for increasing scientific outcomes and encouraging scientists' involvement in future citizen science endeavors. Furthermore, it complements existing work assessing scientific outcomes of citizen science projects (e.g. Ballard et al. 2017; Chandler, See, et al. 2017; Dickinson, Zuckerberg, & Bonter 2010), by taking a cross-analysis approach and providing important insights for future design of citizen science projects.

Our goal in this study is to identify main characteristics, common features and activities in established large-scope citizen science projects that proved to be scientifically productive. Specifically, we focus on a cross-analysis of five projects, which have been chosen, out of 183 projects identified by means of explicit criteria to be presented shortly. We describe the selection process of five projects, the data collection and cross analysis of project characteristics and the recurring themes between projects. The analysis is driven by an assumption that identification of the projects' common characteristics can provide insight and guidance for the future project design.

Scientists' perspective towards citizen science

For scientists, the collection of broad information by citizen scientists, can be extremely valuable in terms of producing new scientific findings (Dickinson et al., 2010). An in-depth review of citizen science projects conducted by Chandler, See, et al., (2017) has recently revealed that existing projects collect data on nearly all essential biodiversity variables, which capture the major dimensions of biodiversity change. These projects cover a broad range of organisms including birds, butterflies, pollinators, mammals, plants and many other species (Roy, Pocock, Preston, Roy, & Savage, 2012). Similarly, in the field of Geographic Information Systems (GIS), large databases are being created combining data manually collected by volunteers with data from physical sensor devices (Boulos et al., 2011). These databases create an elaborated representation of the earth surface, providing information on streets, water resources, health incidence, climate observations and much more (Goodchild, 2007). Together, these datasets combine the best of experts, crowds and machines, and can lead to many new finding, conservation acts and publications (Shirk et al., 2012; Boulos et al., 2011).

For some scientists, the main motivations for engaging in citizen science has to do with promoting their science, rather than engaging the public: they are most interested in opportunities to obtain funding, conduct high-quality scientific research and publish scientific papers (Golumbic, Orr, Baram-Tsabari, & Fishbain, 2017). There are also many scientists who choose not to engage with citizen science, being conflicted by the tension between public engagement and ensuring reliable research conduct (Riesch & Potter 2014). For example, Burgess et al. (2017) found that many biodiversity scientists, which have not used citizen science, have quite low opinions of citizen science as a way to accomplish scientific research.

Furthermore, citizen science practice may be challenging for scientists to engage with, in many respects. Even the most successful citizen science project must deal with logistic difficulties, insufficient expertise of the volunteering participants and concerns about data quality (Conrad & Hilchey, 2011; Dickinson et al., 2010). Scientists also have concerns about losing control over the data, about public involvement in setting goals which could redirect the project focus and about their lack of training in public communication and engagement (Golumbic et al. 2017; van Vliet, Bron, & Mulder 2014). Consequently, it is reasonable to suggest that in order to ensure greater scientists' involvement, the perceived benefits of citizen science must exceed the perceived challenges. Otherwise, citizen science would be drained of its authentic cutting edge science and scientific impact. In turn, this would drain also its social, educational and civic merits.

Different projects have developed diverse ways for dealing with these challenges. In particular, attention was focused on the central challenge of the reliability of the data collected by volunteering amateurs. Kosmala, Wiggins, Swanson, & Simmons (2016) summarize the solutions applied by numerous citizen science projects, such as iterative development of tasks (ensuring a procedure that volunteers can perform successfully without confusion or systematic errors), volunteer training and testing, use of standardized and calibrated equipment, expert validation, replication across volunteers and statistical weighting of volunteer classifications reducing random error and bias. For example, The Monarch Larva Monitoring Project (MMLM-https://monarchlab.org) provides volunteers with workshops and training about the biology of the monarch butterfly and provides hands-on activities to recognize its life cycle and practice the monitoring protocol (Prysby & Oberhauser 2004). Projects on the Zooniverse[1] platform circulate digital images to multiple volunteers, aggregating their classifications to one consensus answer (Clery, 2011; Swanson, Kosmala, Lintott, & Packer, 2016). Overall, several studies (e.g. Haklay, 2010; Gollan et al., 2012; Lintott et al., 2008; Tregidgo, West, & Ashmore, 2013) have demonstrated that citizen science projects are capable of producing reliable data when proper measures are being taken. However, producing reliable data is only one challenge of citizen science projects. Much work is needed in order to design, execute and maintain a citizen science project that would have a chance to become scientifically productive.

Scientific productivity of citizen science

As mentioned, the majority of citizen science projects do not reach publication in peer-reviewed venues (Theobald et al., 2015; Kullenberg & Kasperowski 2016). Rather a small number of projects are generally responsible for most publications in this growing field (Theobald et al., 2015). For example, NestWatch alone had over 40 articles published in scientific journals over the past 15 years, based on their nesting, breeding and monitoring data (NestWatch, 2018).

Recent research has shown that citizen science projects that successfully produce scientific publications are often long-term projects that collect data over a large spatial extent (Kullenberg & Kasperowski, 2016; Theobald et al., 2015). In addition, it is known that projects affiliated with academic institutions have higher rates of publication and are considered more reliable by scientists than projects initiated by

[1] https://www.zooniverse.org/

other organizations and groups (Burgess et al., 2017; Chandler, Rullman, et al., 2017). According to Kullenberg & Kasperowski (2016), the number of projects employing digital platforms for data collection and classification (such as Galaxy Zoo, and Foldit) have increased and have quickly succeeded in publishing results in peer-reviewed journals. Yet, a well-designed digital interface alone, does not seem to be sufficient to achieve successful scientific outcomes or attract long term participation (Cox et al., 2015; Spiers et al., 2019).

Freitag & Pfeffer (2013) investigated recommendations for improving citizen science success using a literature review compared to insights from project coordinators. They highlight three recommendation 1. Collaborate with experts 2. Have a consistent methodology 3. Present data to policymakers and influencers. These recommendations refer to the scientific featurs of projects, and to dissemination of the final results and conclusions. While these points are extremly important, research tells us this may not be sufficient. According to Scheliga, Friesike, Puschmann, & Fecher (2016), scientific success of a citizen science project depend on the ability of the project to recruit and interest participants, maintain long term participation, develop effective volunteer protocols and organize data. Many of these factors are not "scientific" in nature (using the STEM definition - science, technology, engineering and mathematics), but refer to the human, educational and sociological aspects of citizen science. Similarly, Cox et al., (2015) found a relationship between the scientific impact of projects and their public engagement success.

Building on these findings, we focus here on a cross-analysis of selected citizen science projects that have a proved record of scientific productivity. In relation to the selected projects, their nonscientific features were explored, i.e. features related to the project design, management, and public engagement and communication.

We acknowledge, of course, that success in citizen science projects can be defined quite broadly. Definitions of success described in the literature include measures of volunteer participation, data collection, contribution for conservation, social impact and education (Freitag & Pfeffer 2013; Spiers et al. 2019). While each of these outcomes has been studied individually, a combined framework examining the success of citizen science from multiple angles, does not currently exist. Furthermore, as important the above measures of success as they are in citizen science, we choose in this paper to focus on scientific outcomes of the project as a success measure that can encourage greater scientists' involvement. We, therefore, refer to successful projects in the context of this paper, as projects with credible scientific rigor and productivity.

Throughout the paper, we refer to "scientific features" as the core features related to the project discipline and research goals. These include scientific background and rational, data collection methods and protocols for analyzing results. Since the majority of citizen science projects relate to natural or exact sciences (e.g. biology, mathematics, chemistry), often when discussing scientific features, practices from these sciences are highlighted. "Nonscientific features" are referred to as additional project features related to communication, administration, management, and design.

Methodology

In order to reach an integrative understanding of successful citizen science projects, focusing on their nonscientific features, five scientifically productive project were chosen and cross-analyzed. Research stages and selection process of these projects are detailed below.

Considerations for project selection

The initial criteria for projects to be included in this cross-analysis were scientific productivity measured by publications in peer-reviewed scientific journals. Based on findings of Kullenberg & Kasperowski (2016) and Theobald et al. (2015), projects were also sought to be long-term, well-known and cited projects, indicating successful project management and design. In addition, projects from different scientific disciplines (e.g. biology, astronomy, computer science, environment) were sought in order to draw insight from a variety of active projects.

Projects selection process

Seven review papers, published between the years 2009-2016 and containing listings of citizen science project, were used to form an integrated list of operating citizen science projects (Bonney et al., 2009; Dickinson et al., 2010; Franzoni & Sauermann, 2014; Kullenberg & Kasperowski 2016; Science Communication Unit, University of the West of England, 2013; Silvertown, 2009 and Wiggins & Crowston, 2011). A total of 183 projects were present in the aggregated project list, 16 of which were listed in three or more of the reviews (see S1 Appendix). This list does not represent all active projects, nor does it include the newest initiated projects, rather it presents the more long-term and well-established project, that have had the time to produce scientific publications, and therefore fit the considerations for project selection described above. Accordingly, the 16 projects listed in at least three review papers were considered by the authors as well-known and acknowledged, and thus were allocated as candidates for the cross-analysis.

For each of the 16 candidate projects, an extensive search was conducted for academic level publications, using PubMed, Google Scholar and the project website. Relevant publication for this search included articles that had addressed the declared scientific fields and in which the results were based on public participation in at least one step of the research process. For example, for an ecological citizen science project, articles containing species diversity or temporal and spatial distribution results were included. Articles examining educational, social and design outputs were not considered (since they do not demonstrate publications in the scientific field of the project). Projects which had five such publications or less, were excluded from the list (total of six projects). The remaining 10 projects were classified by their scientific fields: ecology, astronomy, meteorology, biochemistry and environmental sciences. Only one project was chosen from each field, resulting with five projects from different scientific fields for the cross-analysis (see table 1): Community Collaborative Rain, Hail & Snow Network (CoCoRaHs), eBird, FoldIt, Galaxy Zoo and Open Air Laboratories (OPAL). A summary of the properties of the five projects selected can be found in Table 1. The selection process is summarized in Fig 1.

Fig 1. Selection process of projects for the cross-analysis.

Data collection

Information about each project was collected from the following sources: (1) Self-reports on the project website; (2) Account of user experience by the first author; (3) information on the project provided in scientific articles produced by the project. At the first stage, the project website was thoroughly examined for information about the project, its goals, research field, participation and data collection options, as well as reports of project outcomes. At the second stage, the first author registered as a participant in the project, learned about its interface and when applicable (depending on the geographical scope of the project), participated as a contributor to the project. This provided a good grasp of the project, its traits and a feel of the user experience. In the third stage, relevant publications describing project administration and outcomes were reviewed for engagement, development and management aspects of each project.

All the information collected was summarized and arranged according to the following aspects: Project description, declared goals, research questions, research field, recruitment methods, data collection procedures and data analysis methods, level of participation, time investment of participants, communication methods and contribution to participants. Our assumption in this paper, is that many of these characteristics may serve as explanatory factors for the success of projects and thus assist with providing guidelines for future project design.

Cross analysis of project characteristics

All the collected data of the five project were summarized, organized in a table and scrutinized by means of applied thematic analysis (Guest, MacQueen, & Namey 2011), which aims to identify implicit and explicit ideas within qualitative data. Using an inductive approach (Thomas, 2006) we systematically compared the data and derived concepts and themes that repeatedly emerged in the projects reviewed. To move the analysis forward from a specific or unique detail to more general concepts, rules or relationships among the themes were identified (Bazelety, 2013). The themes were further clustered using second level coding into four main categories, based on the process they represent: goals, community, platform and dissemination. After identifying these overarching themes, the review summaries of each project were revisited and the existence of each theme was inspected. Table 2 summarizes this process, illustrating the presence or absence of each theme in each project. A brief description of each of the five projects selected (CoCoRaHs, eBird, FoldIt, Galaxy Zoo and OPAL) based on the above analysis, can be found in S2 Appendix.

Table 1. Summary of projects' properties

Project	**CoCoRaHS**	**eBird**	**Foldit**	**Galaxy Zoo**	**OPAL**
Website	https://www.cocorahs.org	http://ebird.org	https://fold.it/portal	https://www.galaxyzoo.org	https://www.opalexplorenature.org
Field	Meteorology	Ecology	Structural biology	Astronomy	Environmental sciences
description	Network for measuring and mapping precipitation	online database for collection and distribution of bird observation	multiplayer online game for identifying protein folding structures	online platform for classifying galaxies	Network of surveys for learning about the environment
Year of establishment	1998	2002	2008	2007	2007
Initiator	Colorado Climate Center at Colorado State University	Cornell Lab of Ornithology and National Audubon Society	University of Washington	Oxford University Astrophysics	Imperial College London
Number of participants	Over 10,000 submitting data **daily**	Over 100,000 submitting over 100 million bird sightings **annually** Over 1 Million visiting **annually**	Over 200,000 players **annually** Over 2,000 players **weekly**	Over 180,000 for Galaxy Zoo 1 During its activity Over 50 Million classifications	Over 500,000 volunteers in **6 years**
Geographic scope	North America	Worldwide, but most substantial in north and central America	worldwide	worldwide	United Kingdom
Number of scientific publications	Over 20	Over 100	Over 15	Over 50	Over 30

Cross analysis results

Fifteen common themes repeatedly emerged in several of the five citizen science projects reviewed in the analysis and were grouped into four categories: goals, community, platform and dissemination (see Table 2). These categories describe projects' emphasis, activities and aspirations, and assist in forming guidelines for future project design.

We refer to *goals* as the projects' explicitly declared aims and envisioned outcomes, including scientific, social and educational ones. *Platform* refers to the interface in which participants interact with the project, submit information, learn about the course and progress of the project and receive training. *Community* refers to ways the projects appropriate themselves to the community of participants and their needs, the addition of community building features such as discussion forums, social media usage etc. *Dissemination* refers to ways by which projects distribute raw data, analyzed and facilitated the presentation of results and publications produced.

Table 2. Four main categories (in grey) and 15 features (in white) which repeatedly emerge in five reviewed citizen science projects.

	CoCoRaHS	eBird	Foldit	Galaxy Zoo	OPAL	Number of projects having a feature
Goals						
scientific goal	X	X	X	X	X	**5**
educational goal	X	X	-	-	X	**3**
social goal	-	X	-	-	X	**2**
platform						
user-friendly platform	X	X	X	X	X	**5**
Smartphone application	X	X	-	X	X	**4**
provides online training and learning opportunities	X	X	X	-	X	**4**
provides learning opportunities offline (workshops)	X	-	-	-	X	**2**
educational materials	X	X	X	X	X	**5**
Community						
Engages existing community	X	X	X	-	-	**3**
does not require previous knowledge	X	-	X	X	X	**4**
provides social platform	X	X	X	X	X	**5**

network of supporting volunteers	X	X	-	-	X	**3**
connection with scientists	-	-	X	X	X	**3**
Dissemination						
raw data available	X	X	-	X	X	**3**
facilitated dissemination of results	X	X	X	X	X	**5**
Total number of features for each project	**13**	**12**	**8**	**9**	**14**	

Legend: (X) means the feature exists within the project, (-) means the feature does not exist within the project.

Goals

All projects reviewed, had a clearly declared scientific goal, each in their field of expertise. Three of the five projects (eBird, OPAL and CoCoRaHS) had also articulated educational or social goals. For example, OPAL's goal is to carry out high quality environmental research with maximum public engagement and to promote environmental local knowledge in the community. While the first part of the sentence demonstrates their scientific goal, the second half emphasizes the engagement and educational goals. These projects have made special effort to facilitate the project in supporting their social and educational goals. This can be seen throughout the analysis and is demonstrated in the other three categories listed below (platform, community and dissemination). To a certain extent the declared goals can serve as predictive factors to the action and activities provided by the projects. In particular, eBird, which has a social goal of providing services and data to the birding community, has built in tools in their platform that appeal to this specific volunteering community. OPAL has designed picture guides and easy tasks that are accessible to all ages, group and communities and CoCoRaHS organizes face-to-face workshops and working teams.

Platform

Another important feature identified in all projects reviewed, is a simple, user-friendly platform for collecting data. Whether the data source is from physical collection (CoCoRaHS, eBird, and OPAL) or derived from online platforms, (Foldit and Galaxy Zoo) the interface is always very user-friendly and intuitive. Although some projects require registration and some do not, once ready to submit data, the process is easy and clear.

Four of the projects (CoCoRHas, eBird, Foldit and OPAL) provide online learning materials, in the form of videos, tutorials, manuals and work guides, and two projects have additional face to face workshops (CoCoRHas and OPAL). OPAL, in particular, has invested greatly in providing clear and accessible information directed to participants from all ages backgrounds and abilities. In addition to pictures and short videos, OPAL provides tips for things to look out for and conditions that could be confused with what is being monitored. For example, while monitoring Oak mildew, a plant disease that infects young oak leaves and shoots, OPAL gives the tip not to be confused with other powdery mildews on other plants that are different species of the same disease (OPAL, 2017). eBird in addition to specific learning materials on its web site, has supplementary resources provided online by the Cornell lab of ornithology. These include the "all about bird" guide (www.allaboutbirds.org) and the recent smart phone application Merlin Bird ID (http://merlin.allaboutbirds.org), which supports birders in identifying birds in their region.

All five projects offer additional educational materials online, providing teachers and educators opportunities to implement the use of the platform in their classroom. These include lessons plans and learning resources for student of different grades and ages. Foldit, for example, offers the option to create private groups and contests, providing teachers with the opportunity to view the activity and achievements of all members of their group.

Community

Three projects (CoCoRHas, eBird and Foldit), are built on an assumption that communities of interest exist in their field, and direct themselves towards the existing communities. Namely, the projects appeal to the specific needs of the existing community, a process, which makes it easier to recruit participants. In the case of eBird, services were designed to attract birding communities, in their process of finding and identifying birds. These services enable participants to keep track of personal bird observations lists, while providing exposure to all bird observations by time and location and giving recognition for individuals' work (Sullivan et al., 2009). According to Sullivan et al. (2009), the attention to the existing community needs has resulted in extensive growth of eBird, both in terms of the number of participants and the amount of data submitted. Foldits' initial recruitment was done through the Rosetta@home community, a distributed computing project that was initiated by the same research group. This step influenced and assisted the recruitment, as the Rosetta@home community was already interested in protein folding issues (Cooper, Khatib, & Baker, 2013).

Still, participation in four of the five projects (CoCoRHas, Foldit, Galaxy Zoo and OPAL) does not require having prior knowledge in order to participate. Participation with no previous knowledge expands the diversity of volunteers and allows people, who are not experts, to participate and contribute. This was made possible due to projects' clear interfaces and the accessible tasks (as described in the platform category). In Galaxy zoo, for example, submitting information is done simply by looking at telescope pictures and answering a series of questions as to the shape of the image in the picture (e.g. smooth, rounded, disk shape etc.).

An important feature found in all five projects is the promotion of social interactions among participants facilitated by online forums, chat rooms and other social networks tools. These tools enable participant to share their findings, have discussions and ask questions. They also serve as community building tools enabling collaborations, exchange of strategies (e.g strategies for folding proteins in Foldit), provide learning opportunities from others experiences and promote social relationships and enjoyment.

An additional empowering feature found in three of the projects (Foldit, Galaxy Zoo and OPAL) is easiness of connection to the scientists who initiated the project. This is done during scheduled chats with scientists, where participants can communicate directly with the people working behind the scene, ask questions and get better insights as to the uses of the data and its analysis process.

Furthermore, organizing huge databases and constant flow of information can sometime be too much for a local group to manage. For this reason, three projects (CoCoRHas, eBird and OPAL) have a local network of volunteers participating in additional tasks of management, data verification and training. CoCoRaHS for example, has volunteers involved as local county coordinators, in preparing training and educational materials, organizing training sessions, recruiting volunteers etc. While Foldit and Galaxy Zoo do not have a network of supporting volunteers, they do have experienced volunteers who can take leading roles in promoting the research. For example, in Galaxy Zoo, experienced volunteers lead meaningful conversations in the project forum, highlighting interesting sightings and assisting image identification.

Dissemination

Dissemination of the results in blogs, newsletters or reports is available in all five projects. The texts on the results of the projects are always written in a clear and accessible fashion. Some projects have a "message of the day" or "volunteer of the month" feature, with additional general or personal information presented. This feature seems incredibly important in providing feedback to volunteers and updating them about how their data was used. Four of the five projects (CoCoRHas, eBird, Galaxy Zoo and OPAL) also have an option to view full data sets in the form of interactive maps, charts and tables, excel data sheets that can be downloaded. Volunteers can analyze the data, identify trends and interesting phenomenon and pursue their own research questions. eBird alone has received over 2000 requests for full data-set downloads, over a period of 21 months (Sullivan et al., 2017). These datasets could also be used by the professional community and serve for secondary analyses (the use of data collected for a prior study, in order to pursue a new research interest).

Summary for successful project design

Taking a close look across the five projects discussed and the 15 common features described here, we recognizing their social emphases and user-centered approach. These features may contribute to project productivity, acknowledgment and success.

Summarizing this cross-analysis raises a number of ideas that could assist the design of future projects. These consider the end user of these applications who are the members of the public that citizen science projects try to attract. We believe the information presented above can be summarized as a set of heuristics for planning successful citizen science projects. This is not an attempt to provide complete instructions for citizen science projects design, but rather exemplify the finding from this study:

1. Platform- Creating user-friendly interfaces – interfaces that are simple and intuitive turn the process of submitting data into an easy and even enjoyable task. Such interfaces can attract and retain participants, and in many ways they shape the unique identity of the project.
2. Platform- Planning simple tasks accompanied by training activities - Tasks that participants are asked to perform should be modest and easy to perform, preferably with no need in prior knowledge. The training can be provided in a number of formats addressing different preferences of the participants (e.g. printable guides, online videos or personalized workshops).
3. Community- Addressing existing communities of interest - Identifying and addressing a community need, and targeting existing communities with the potential of further development can ease the challenging process of recruiting participants. It can further facilitate the community interest as well as justify the need for the new initiated project.
4. Community- Supporting community building in connection with scientists – Providing participants with discussion forums on the website of the project or through Facebook and other social media can support community building and participant retention. The availability of scientists to answer questions, join discussions and be open to hear new suggestions and receive feedback can further promote participant motivation.
5. Dissemination- Making the data available – Participant are interested in knowing what scientific output their participation resulted in. Data or data summaries should be available in clear, facilitated fashion, in a way citizen scientists could understand. This may include dissemination of final results in a blogs, newsletters or reports in addition to providing full data sets using interactive maps, charts and tables.

It should be noted that following these heuristics does not guaranty project success. Additional aspects, such as the design of scientific protocols for data collection and analysis are important factors contributing to the individual scientific success of citizen science projects.

Discussion

This study's goal was to qualitatively identify characteristics of scientifically successful citizen science projects, for the sake of designing the future citizen science projects. Examining ways to design citizen science projects has been a focus of many recent publications (e.g. Aristeidou et al., 2017; Sturm et al., 2018; Wald, Longo, & Dobell, 2016). Many of these publications conclude with recommendations for increasing "success", yet the perceptions of success in citizen science projects often vary between projects and researchers. Depending on the goals of the project and on the perspective taken by the initiators and the participants, success may be related to collecting and analyzing scientific information as well as to education, conservation, stewardship, and community-building (Freitag & Pfeffer 2013). This paper refers to "success" of a citizen science project in relation to the project scientific productivity in terms of publications in peer-reviewed scientific outlets. This choice was made based on evidence that only a small number of projects produce publication in peer-reviewed journals, though an opportunity to produce scientific publications is one of the main factors for many scientists when considering their involvement in such endeavors (Golumbic et al., 2017). Our qualitative study relies on an assumption that analyzing nonscientific aspects (e.g. communication, administration, management, and design) of scientifically productive projects may provide insight into the methods of success that would be useful as design heuristics for future projects.

While some overviews of citizen science projects exist and include the characterization of successful traits (e.g. Follett & Strezov, 2015; Kullenberg & Kasperowski, 2016; Theobald et al., 2015 and Tulloch et al., 2013), they are mostly based on statistical qualities such as number of publications. Here, the initial selection process was indeed quantitative and based on a similar approach. However, a qualitative analysis provides deeper insight into project characteristics and features. Kullenberg & Kasperowski (2016), for example, applied a scientometric approach (an analysis of quantitative features of scientific research) to quantify citizen science projects with scientific output. They reveal that projects which have the largest number of published papers are either long term projects (over 30 years) with large dataset or more recently established projects, which employ digital platforms for collecting observations. Our study supports these findings, but also examines these digital platforms in depth, providing insight into their design and ways of operation of the platforms.

We reviewed and analyzed five prominent citizen science projects (CoCoRaHs, eBird, FoldIt, Galaxy Zoo and OPAL), focusing on the communication, management, design and public engagement activities. Among common features of these projects, we found that beyond scientific productivity, all projects have a strong user-centered approach and social emphasis. This is achieved by using user-friendly interfaces, easy platforms for collecting data, online videos, tutorials, and work guides, social platforms and facilitated dissemination of results. Many of these features and in fact science and environmental communication practices, which encourage and motivate participants to continue to participate and contribute to the on-going research. These findings reinforce and extent findings by Baruch, May, & Yu, (2016), who have claimed that platforms which did not provide feedback and training to participants and avoided dissemination of results, were in risk of losing their volunteers. Furthermore, disseminating citizen science data in a clear and useful way has been instrumental in public understanding and use of its information (Golumbic, Baram-Tsabari, & Fishbain 2019) and is important for understanding environmental risks (Kuchinskaya, 2018).

While volunteers' initial motivation for participation in citizen science may vary, their decision to continue this engagement is directly related to their experiences (Rotman et al., 2012). From the analysis presented in this study, a picture is formed as to the features that help retain secondary motivations and hence, contribute to the creation of scientifically successful citizen science projects. Since most contributions in citizen science are attained by returning participation (Sauermann & Franzoni 2015), secondary motivations are extremely important to preserve. Putting the scientific aspects aside, project initiators should consider the end user of the platforms and their respective needs and interests.

Two of the projects reviewed - Foldit and Galaxy Zoo - were exceptional in many of the features identified and had the fewest common features among the projects reviewed (nine and eight respectfully, out of fifteen features). Neither have social or educational goals, nor an existing community of amateurs or a network of supporting volunteers. This may be due to the unique characteristics of the projects, which do not collect physical data from the public, but rather derive the data from the active online participation of volunteers in solving tasks of scientific importance. Galaxy Zoo and Foldit are defined by Wiggins & Crowston (2011) as virtual projects rather than investigative projects, which mean they use advanced technological tools to create online tasks for data collection. Virtual projects work effectively with large numbers of volunteers, and time and effort invested by participants may vary compared to investigative projects. Hence, success of these projects require additional explanation. Pocock et al. (2017) pointed out that computer-based projects, such are Galaxy Zoo and Foldit, are distinctly different from other citizen science projects in terms of their methodological approach and complexity of the citizen science activity. Raddick et al., (2013) found that participants' motivations in Galaxy Zoo were mainly to contribute to science and be exposed to beautiful photos. The motivations of community, teaching, and learning were less important to volunteers, at least at the initial stages of involvement. Similarly, Nov, Arazy, & Anderson, (2011) found that collective motives - the importance attributed to the project's objectives - were highest among Stardust@home and SETI@home volunteers (both virtual projects), second by intrinsic motivation which refer to the enjoyment associated with participation in the project. This suggests that the unique characteristics of virtual projects attract participants with different motivations than investigative projects and hence, may have unique implications that need to be considered throughout the design process.

Study limitation and suggestions for future research

This paper builds on existing literature, on self-description of citizen science projects and on personal experiences with their platforms. Though we have argued that the presented features and design heuristics are fundamental for project success, we realize these features should be examined more broadly, by looking at many more successful and unsuccessful projects and by documenting first-hand experiences of citizen scientists. Additionally, inclusion of interviews with the five project leaders may have provided internal perspectives for the design principals used in designing these projects and confirmed some of the assumptions made in this paper. However, we have deliberately decided not to include such interviews, since often design choices are based more on intuition rather than intentional grounded decisions (Ren & Kraut 2014). Furthermore, performing the above analysis by an external observer who is not associated with the projects, and is not familiar with its design principals can provide a fresh, unbiased perspective. This could offer a fresh point of view (as we believe is the case in this study) that assists with identifying and recognizing aspects and that are not necessarily seen from within.

It should also be noted that successful projects were defined in this paper as projects with credible scientific rigor. Other forms of success exist, such as contribution for conservation, governmental plans and education, which were not considered in the scope of this paper. Additionally, measuring success of projects should ideally be done by considering projects' specific goals and assessing the extent to which these have been achieved. However, this paper was not aimed at assessing citizen science success in general terms but rather with the specific focus on scientific productivity as a success measure for encouraging greater scientists' involvement in citizen science. Future work could explore the design of citizen science projects using a holistic approach to success, examining successful implementation of mutual goals.

Concluding remarks

Professional scientists turn to citizen science in order to create or get access to large-scale and comprehensive data sets. Citizen scientists, on the other hand, join in search of opportunities to broaden their horizons and allow them to engage in an enjoyable activity. It is the synergy between the desires of citizens and the desires of scientists that support the collaboration between the groups (Rotman et al., 2012). Creating a mutualistic environment, in which each group benefits from the activity of the other group and everyone profits, could further promote citizen science and participation (Sagy et al., 2019). Creating such an environment is a difficult endeavor (Golumbic et al., 2019), yet, as the presented cross-project analysis suggests, it is an important investment. We conclude that in order to successfully plan and execute a citizen science project, a holistic practice may be adopted. This practice considers both scientific excellency in terms of methodology, statistical analysis and data quality, alongside public engagement and science communication features.

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