The Challenge of Evaluation: An Open Framework for Evaluating Citizen Science Activities

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Abstract

In today's knowledge-based society we are experiencing a rise in citizen science activities. Citizen science goals include enhancing scientific knowledge generation, contributing to societally relevant questions, fostering scientific literacy in society and transforming science communication. These aims, however, are rarely evaluated, and project managers as well as prospective funders are often at a loss when it comes to assessing and reviewing the quality and impact of citizen science activities. To ensure and improve the quality of citizen science outcomes evaluation methods are required for planning, self-evaluation and training development as well as for informing funding reviews and impact assessments. Here, based on an in-depth review of the characteristics and diversity of citizen science activities and current evaluation practices, we develop an open framework for evaluating diverse citizen science activities, ranging from projects initiated by grassroots initiatives to those led by academic scientists. The framework incorporates the social, the scientific and the socio-ecological/economic perspectives of citizen science and thus offers a comprehensive collection of indicators at a glance. Indicators on a process- and impact-level can be selected and prioritized from all three perspectives, according to the specific contexts and targets. The framework guides and fosters the critical assessment and enhancement of citizen science projects against these goals both for external funding reviews as well as for internal project development.

1. Introduction

Citizen science is a globally growing phenomenon that bridges science and society. The bridging pillars are based on the active engagement of citizens in scientific activities and processes (Bonney et al. 2009). Citizens join as active contributors in research, addressing both societally relevant as well as fundamental research questions. Via their voluntary engagement in research they can also contribute to evidence for policy evaluation and development (Rowland 2012; Haklay 2015).

Citizen science offers different levels of participation, from contribution of citizens in structured tasks led by scientific organizations, to the active collaboration and joint co-design and co-production of research with scientific partners, up to completely independent projects driven by citizen-led initiatives (Bonney et al. 2009; Shirk et al. 2012, Wiggins and Crowston 2015). A significant characteristic of all forms of participation is the great degree of dedication that participants reveal in order to delve deep into a research topic together with scientists and/or other volunteers.

Currently, we are experiencing an exponential rise in citizen science projects (Kullenberg and Kasperowski 2016) associated with wider acceptance of the manifold benefits and innovation potential of citizen science in science, society and policy. Contributions from citizen science activities such as large scale data sets or novel forms of data sets have already made a significant impact on environmental research (e.g. Silvertown et al. 2011; Sullivan et al. 2014) and biological science (Eiben et al. 2012, Curtis 2014). In the humanities, citizen science is also starting to be recognized as a potential promise of creativity but is not yet fully discovered nor put into practice (Dobreva and Azzopardi 2014). Moreover, citizen science can contribute to transformational change in science and society. We find indications about such possible impact e.g. in the formulation of new research questions by both, the members of the public and the scientific community (e.g. extreme citizen science (Da Cunha 2015)) or in the joint finding of solutions to regional (e.g. Lee et al. 2006), national and even global (Theobald et al. 2015) problems of societal and scientific relevance. In addition, citizen science can attract more scientists into trans-disciplinary work (Poliakoff and Webb 2007), as it provides opportunities to encounter a variety of knowledge domains and new perspectives. It can offer new forms of science communication as well as new partnerships. Citizen science can also contribute to learning about the processes of scientific enquiry and to getting a deeper understanding of scientific outcomes (Risch and Potter 2014; Bela et al. 2016; Richter et al. 2016). This in turn may lead to an improved understanding, uptake and implementation of transparent and responsive research in society. In this way, citizen science is an approach that encourages stewardship, fosters empowerment and contributes to responsible research and innovation (RRI) (Sutcliffe 2011; Wickson and Carew 2014).

All in all, the greatest innovation potentials of citizen science are in line with calls for open science (e.g. European Commission 2016) , such as the opening and expanding of (new) views and perspectives in science; the broadening of participation in science, e.g. via Internet and social media (e.g. Pace et al. 2010); the development of innovative technology and concepts for data collection and validation (e.g. Bonter and Cooper 2012; Dickinson et al. 2010); the establishment of data standardization (e.g. Ottinger 2010) and data storage (archives); the integration and harmonizing of existing data as well as the realization of time-consuming research across large temporal and spatial scales. Co-production of research can create trustful relationships between members of society and science (e.g. Suomela 2014) and enhance the capacity for the joint evaluation of science and scientific findings (Richter et a. 2015, McKinley et al. 2015, Bonn et al. 2016). Emerging grass-roots initiatives, embedded in the local context, can also support and provide encouragement for citizen science initiatives that have a greater focus on social innovation and social change. Community-driven initiatives, such as OpenStreetMap.org, emphasize local knowledge production and aim at community benefits rather than pure scientific outcomes, broadening the innovation potential from a socially-driven community perspective.

To promote and harness these innovative citizen science potentials adequate funding mechanisms are required (Schäfer and Kieslinger 2016) and should be targeted to support these goals. As a vital part of every effective project management, external and internal evaluation plays a pivotal role to inform internal operations as well as funding management. Sound evaluation procedures and criteria are needed to assess the impact of citizen science activities for science, society and policy. These include accountability of the project to the participants, the public and potential funding agencies. The focus of accountability will vary depending on project goals and settings, e.g. between large scale academia led citizen science projects that need to show, amongst others, scientific outcomes in the form of peer-reviewed journal publications to crowdsourced geographic information projects, that may deliver e.g. broad but quick maps for natural disaster relief work. These evaluation criteria are rarely developed but are needed to inform proper citizen science funding support and effective project management.

1.1 Evaluating Citizen Science

In line with the wider and growing appreciation of citizen science, and the establishment of new funding schemes for citizen science activities such as OPAL for the UK (Imperial College London, 2016), the TOP CITIZEN SCIENCE program in Austria (Zentrum für Citizen Science, 2016), or the new explicit citizen science funding scheme in Germany by the Ministry of Education and Research (BMBF), there is a need to establish evaluation criteria. To create a culture of evaluation, measures need to be in place to support the proof of concept appraisal, the internal mid term reviews as well as the final impact assessment of citizen science activities.

Evaluation should assess the value of citizen science for different outcomes and / or processes. This comprises a systematic assessment of both the effectiveness and efficiency of an activity or program against a set of explicit or implicit standards and criteria (Weiss 1989). While outcome-based evaluation is concerned with assessing the overall goals of the activities or programs and the benefits to the participants and recipients of results, process-based evaluation identifies the activities' or programs' operational strengths and weaknesses. Thus, evaluation can be understood as an investment to improve a program or activity by producing programmatic self-understanding and self-accountability. Similar to Wickson and Carew's (2014) approach for defining quality criteria for Responsible Research and Innovation (RRI), it is important for the development of a citizen science evaluation framework to decide whether the evaluation focus should be on i) institutional and interpersonal preconditions for successful projects, ii) the operational process, iii) the final products and outcomes of the projects, or iv) a mixed approach.

In this paper, we present a framework with a set of evaluation criteria focusing on both the process and outcome level of citizen science projects, developed through intensive consultation. This open framework is designed for project managers and funding bodies to inform the planning of citizen science activities, the ex-ante evaluation of project funding as well as internal mid-term and ex-post evaluation of project impact with regards to scientific advancement, citizen engagement and social impact.

2. Methodological Approach towards Evaluation Criteria for Citizen Science

The presented catalogue of evaluation criteria is the result of an intensive review of existing projects and literature, as well as an in-depth analysis process including stakeholder consultation, expert interviews, and iterative adaptation and additional feedback loops with actors in the field. The process was led by two working groups focusing on the social sciences and natural sciences, respectively. The process was initiated in July 2015 and the criteria catalogue has undergone a circle of refinement (see Figure 1).

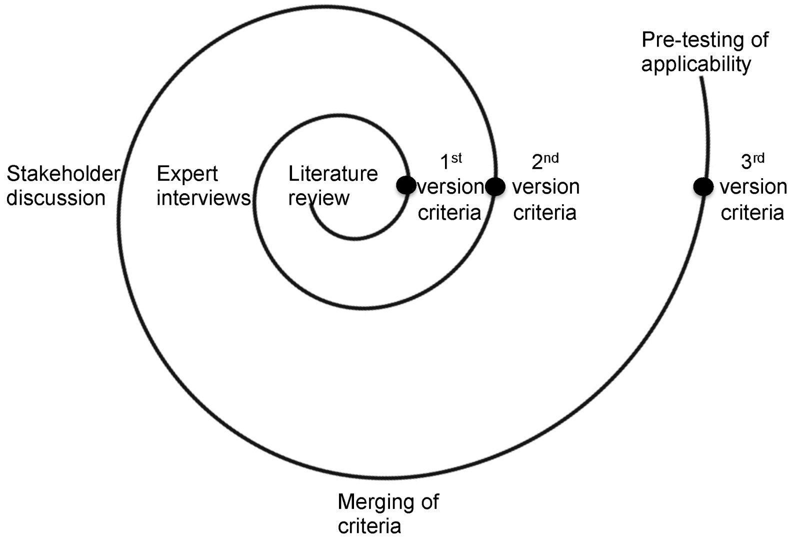

Figure 1: Methodological approach of developing the evaluation framework

A narrative literature review (Meyer 2009) of the different evaluation approaches that are currently in place for citizen science projects was conducted, using various databases, such as Scopus, Web of Science and Google Scholar as well as the library of the University of Natural Resources and Life Sciences, Vienna. In addition, the authors searched for practical evaluation guidelines in the Internet, by screening websites from citizen science organizations worldwide and websites that provide access to citizen science resources and projects (e.g. www.buergerschaffenwissen.de, scistarter.com, Citizen Science Central from the Cornell Lab of Ornithology). Our analysis of current evaluation practice focused mainly on areas in which citizen science projects differ from non-participatory scientific projects, such as communication, learning, technology participation and data management. The insight gained via the detailed exploration of the literature (summarized in Table 1) and personal expertise of the authors with citizen science projects first led to two parallel draft versions of evaluation criteria for social and natural sciences.

In a next step ten experts from Austria and Germany were consulted during August 2015 with in-depth semi-structured interviews and written feedback via email in order to review the first draft versions of the criteria set. The experts were selected based on their different approaches towards citizen science, covering practical as well as theoretical and evaluation specific expertise. Three of the consulted experts are key persons in the creation of the platform “Citizen Create Knowledge” in Germany and the elaboration of the Citizen Science Strategy 2020 for Germany. Their expertise is based on practical experiences from citizen science projects, as well as their research on science communication and citizen’s involvement in research. Two experts lead science communication initiatives, one in Germany and one in Switzerland. One expert manages a citizen science project herself and counts responsible for integrating citizen science in Austrian curricula, while another expert coordinates a citizen science training course. Two experts contributed with their expertise in evaluating science-, technology- and innovation-policy and their profound experiences from the work with and for public authorities and funding agencies. Finally, one expert contributed his knowledge in technology assessment and the protection of privacy, which is highly relevant for citizen science.

The aim of this expert consultation was to collect expert feedback on scope, completeness, usefulness and applicability of the draft versions of the criteria set. Oral consent was given during the interviews and the obtained data was analyzed anonymously and no personal data of participants was collected. As a result of this step the criteria catalogues were refined and the revised versions with integrated feedback were then discussed in a half-day stakeholder workshop to gain deeper insights from two stakeholder groups: representatives of citizen science projects and public administration. The stakeholder workshop was conducted with 20 representatives of Austrian citizen science projects and four representatives of the funding body, the Austrian Federal Ministry of Science, Research and Economy. This was an important step in the process to enhance relevance and applicability of the framework.

The feedback from the stakeholder discussion was documented in an anonymized way in meeting minutes and the two approaches were merged into one catalogue, integrating the feedback from the workshop. Three core dimensions for evaluation emerged: science, citizens/actors, socio-ecological/economic systems (See Table 2).

The iterative cycle of elaborating and fine-tuning evaluation criteria with stakeholders (Fig 1), led to an integrated version with increased relevance and remit for the actors (Table 3).

3. Results

3.1 Citizen science evaluation

There are currently no commonly established indicators to evaluate citizen science, and individual projects are challenged to define the most appropriate road towards collecting evidence of their impact. While some experts tend to focus on the learning gains at the level of individual participants (e.g. Phillips et al., 2014) others concentrate evaluation on their scientific gains and socio-ecological relevance (e.g. Bonney et al., 2014; Jordan, Ballard and Phillips, 2012, Tulloch et al. 2013). Only Haywood and Besley (2014) made a first attempt towards an integrated assessment framework by combining indicators from science education and participatory engagement. Still, the general consensus seems to be to focus evaluation on the main stated aims of the project.

Bonney et al. (2009) recommend a two-way evaluation focusing on the scientific outcomes of the projects (e.g. number of papers) and the learning effects for the participants (e.g. improved skills). They suggest applying different evaluation methods, such as pre and post project surveys or examination of the mail correspondence between participants and project coordinators. The evaluation of the scientific impact of projects is challenging, since many evaluation approaches exist and many of them are criticized for their shortcomings (e.g. number of papers, citation impacts) (e.g. Allen et al. 2009; Hirsch 2005).

Some very practical recommendations on how to evaluate citizen science projects have been suggested by Tweddle et al. (2012) and Phillips et al. (2014). The evaluation criteria suggested e.g. by Phillips et al. (2014) to assess individual learning outcomes include gains in scientific knowledge or skills as well as wider personal impact on a person's behavioral change, their interests in science, motivation and self-efficacy to participate in science. Aspects addressed under the heading of behavioral change, such as taking stewardship and civic action, which all point towards social implications, are also covered by other authors (Crall 2011). Experts recommend not applying all criteria equally in a single project, but rather to define learning goals and expected learning outcomes at the beginning to develop an appropriate evaluation strategy, aligning measurable indicators (Jordan et al. 2012; Phillips et al. 2014; Tweddle et al. 2012). Learning outcomes should be aligned to the different target groups and their pre-existing knowledge and skills. Otherwise the project evaluation runs the risk of not being able to properly assess the learning gains of individuals and to document genuine impact (Skrip 2015).

Evaluation methods centered around demonstrating potential impact on the individual participating citizens are common (e.g. Brossard et al. 2005, Randi Korn 2010). Data tends to be collected via surveys, interviews and the analysis of personal communication with the participants (Gommerman and Monroe, 2012).

Although personal development of the citizen scientists is an important aspect of any citizen science projects, evaluation approaches concentrating exclusively on personal learning outcomes can be regarded as too narrow and miss out other important aspects of citizen science, such as the wider societal or scientific impact. Shirk et al. (2012) therefore recommend a more holistic approach to project evaluation, considering the impact on the scientific knowledge gain, the individual development as well as broader socio-ecological/economic impact and thus considering societal, ecological, economic and political influence factors during the evaluation process.

In a similar vein, Jordan et al. (2012) promote evaluation that goes beyond learning outcomes and suggest assessing also programmatic and community level outcomes. Their suggestions for a more comprehensive approach to evaluation stress the potential impact of citizen science on social capital, community capacity, economic impact and trust between scientists, managers and the public. According to the authors an evaluation on the three levels – individual, program and community - may ultimately contribute to socio-ecological system resilience.

Evaluation approaches applied in science communication activities (e.g. Skrip 2015; Irwin 1995; Finke 2014) also reveal relevant aspects for evaluating participatory processes. Special attention should be paid to the clear definition of the selected target groups, bi-directional communication and the transfer of responsibility and ownership.

Overall, Wright (2011) emphasizes the role of evaluation in adaptive project management. Continuously sharing experiences and lessons learned across the various stakeholders supports the social learning process and contributes to an iterative improvement of citizen science projects and programs. Skrip (2015) and Dickinson (2012) also suggest an iterative evaluation during the course of the project complementing adaptive project management in order to allow for flexibility and the possibility to counteract an undesirable project development.

Despite these individual efforts of authors (summarized in Table 1), experts seem to agree that citizen science projects currently lack in evaluation and experience sharing. Comprehensive evaluation frameworks that would allow for comparability across projects and programs are missing (Bonney et al. 2009, Bonney et al. 2014, Crall et al. 2012). This makes it difficult to show the direct and indirect impact of citizen science on society and the environment (Jordan et al. 2015). A recently published study discussed the request from citizen science stakeholders for flexible evaluation strategies that adapt to the specific project contexts (Schäfer and Kieslinger 2016). Across the world, initiatives have started to work on support measures for citizen science projects to build capacity, guide citizen science development (e.g. Pocock et al. 2015, Pettibone et al. 2016) and professionalize evaluation. For Europe a Citizen Science White Paper has been developed (Socientize 2015) and in Germany, the citizen science capacity building project "Citizens create knowledge – knowledge creates citizens (GEWISS)" recently developed a Green Paper on the Citizen Science Strategy 2020 for Germany (Bonn et al. 2016). Both call for guidelines and indicators for project evaluation. In Austria, the Federal Ministry of Science, Research and Economy, is developing concepts for project evaluation to be applied in their new funding programs. The European Citizen Science Association (ECSA) has taken first important steps by developing ten principles of citizen science (ECSA 2016) that align with the evaluation criteria presented in the next chapter.

Table 1: Summary of main evaluation categories and methods for outcome focused assessments of citizen science projects, based on literature review

Outcome focus	Discussed and described in (exemplary selection)	Attributes[1] of the evaluation	Measures[2] of the evaluation	Actors/ objects involved in evaluation
Learning outcomes	Tweddle, J. et al. 2012	Before and after assessment	• Improved skills • Knowledge gain • Personal development • Behavior change	Participants
Learning outcomes	Phillips, T. et al. 2014	Summative evaluation (evaluation report based on an evaluation plan and evaluation questions) Self-reports or observations	• Self-efficacy for science • Self-efficacy for environmental action • Increased motivation • Behavior change • Development of stewardship • Skills, knowledge and interest in and for science	Practitioners, project leaders/coordinators, educators/outreach specialists

Learning outcomes	Bonney et al. 2009	Qualitative and quantitative measures • pre- and post project surveys • surveys of self-reported knowledge gains • interviews with focus groups	• Duration of involvement • Numbers of participants • Improved and enhanced understanding • Better attitude • Skills and interests • Examinations of e-mail and listserv messages	Participants
Scientific outcomes	Bonney et al. 2009	As above	• Numbers of papers published • Numbers of citations • Numbers of grants received • Size and quality of citizen science databases • Numbers of theses • Frequency of media exposure	As above
Socio ecological outcomes	Jordan et al. 2012	Not explained	• Enhanced social capital • Community capacity building • Economic impact (job creation) • Creation of trust between public and scientist, and land managers • Development of resilience of the socio-ecological system	Community
Communi-cation outcomes	Skrip, M.M. (2015)	Evaluation (proposed/ not proposed) of broader impacts outreach activities	• Identification of audience • Understanding of the needs of the audience • Consideration of audience identity • Two-way communication with knowledge building capacities • Collaboration with communication experts	Project proposal Proposers, reviewers

[1] Attributes provide context to measures.
[2] Measure is a value on which some sort of analysis can be performed.

3.2. Evaluation criteria

Our criteria catalogue structures evaluation criteria along three main dimensions of participatory scientific processes -*scientific aspects, individual actor, and socio-ecological/economic system* - (Holocher-Ertl and Kieslinger 2015). For each of these dimensions we propose criteria to be applicable at "process & feasibility" level as well as at "outcome & impact" level in the matrix presented in Table 2.

Table 2: Dimensions and main categories of the citizen science evaluation framework

	Process & Feasibility	**Outcome & Impact**
Scientific dimension	● Scientific objectives ● Data & systems ● Evaluation & adaptation ● Cooperation & synergies	● Scientific knowledge & publications ● New research fields & structures ● New knowledge resources
Citizen scientist dimension	● Target group alignment ● Degree of involvement ● Facilitation & communication ● Collaboration & synergies	● Knowledge & attitudes ● Behavior & ownership ● Motivation & engagement
Socio-ecological/economic dimension	● Target group alignment ● Active involvement ● Collaboration & synergies	● Societal impact ● Ecological impact ● Wider innovation potential

This matrix can be applied to citizen science proposals for (a) strategic planning and funding assessments, for (b) monitoring progress during the project duration and for (c) impact assessments at the end of the activities. In the course of the project lifecycle the emphasis of evaluation would gradually shift from the process view to the product or impact view. The process & feasibility view makes sure that projects prepare a fruitful ground for the upcoming activities, via e.g. concepts, methodologies, adaptable planning etc. and thus is key during the starting phase. The outcome & impact view comes into play when first effects on science, individuals and socio-ecological/economic systems should be measured. In the following we shortly present each of the three dimensions.

3.2.1. Scientific dimension

Indicators on the *process level* analyze the scientific grounding of the citizen science project. A clearly defined and genuine research question, which is apt for citizen science approaches and meets the interests of participants (whether of societal relevance or meeting basic scientific curiosity), is the scientific basis of all future activities. Conceptual approaches such as research ethics, the proper management of (open) data as well as intellectual property right issues need to be addressed from the beginning. Similarly, proper data quality control and validation processes are crucial success factors. Progress monitoring that allows for flexibility and may lead to adaptive management during the project constitutes an important element during the process. The analysis also pays credit to new forms of collaboration amongst societal actors and groups and considers, where appropriate, the sustainability of collaborations between citizens and scientists.

On the *outcome level*, projects need to be evaluated also according to traditional academic standards, such as the generation of genuine scientific knowledge, captured in publications and possibly leading to new projects. It may need to be discussed to what degree a similar level of publication impact needs to apply, considering the other multiple benefits of citizen science projects and the added time resources needed. In addition, indicators should also assess the project impact on institutional or organizational structures and new forms of integrating traditional and local knowledge and thereby facilitating true knowledge exchange between science and society.

3.2.2 Citizen scientists dimension

On the *process level*, projects need to carefully design engagement and communication strategies. These need to cater for different participant groups in terms of levels of engagement, interactive support measures and training, to facilitate successful participation of individual citizen scientists and collaboration with academic researchers. Working with civic society organizations may allow for working with specific target groups and individuals with a genuine interest in the topic.

When it comes to assessing the *outcomes and potential impact* at the individual level, the personal learning and development gains are key. Did the participants develop any new knowledge or skills during their participation and does that increase their understanding and attitude towards science? Did they enjoy the project and or gain personal satisfaction through the possibility of contributing to science and possibly to (local) policy development? Personal gains amongst individual participants may lead to changes in attitude and behavior as well as an increased ownership, while participation of young citizens may rise their interest in embarking on a science career.

3.2.3 Socio-ecological/economic dimension

Looking at the wider social, ecological and economic conditions for successful citizen science projects, appropriate means for dissemination and outreach activities need to be considered at the *process level*. Key stakeholders need to be engaged in a bi-directional dialogue to foster ownership and participation. For wider visibility and impact seeking collaborations with e.g. civil society organisations tend to be very useful.

At the *outcome level* the wider societal impact should be assessed in terms of a contribution to increasing civic resilience, social cohesion and social impact. Depending on the project a focus on environmental or economic impact might be traceable as well. The wider innovation potential of citizen science should be addressed against contribution to societal transformation and sustainability goals.

In the overview table (Table 3) we match the overarching criteria with supporting questions to qualify and elucidate evidence for each criterion. These questions have been developed through the literature review and critical deliberation process of the expert interviews and stakeholder workshop. The nature of the supporting questions presented in Table 3 is such that they offer guidance for planning, monitoring and assessing citizen science projects and have a reflective purpose. As such the selection of the supporting questions should be tailored to the specific projects or programs. For assessment methods, we recommend a mix of qualitative and quantitative methods, such as online surveys, usage statistics, interviews, focus groups, etc. to collect the necessary data to provide evidence for answering these questions. The evaluation instruments need to be embedded in a solid evaluation plan tailored for each project, that may include concrete benchmarking of measurable targets to assess success during and after the project.

Table 3: Evaluation criteria and supporting questions (derived from literature review and proper experiences, critically reflected in expert interviews and stakeholder workshop)

	Criteria	Supporting questions
Scientific dimension	***Process and Feasibility***	
	Scientific objectives	
	Relevance of scientific problem	• Does the project adhere to the definition of citizen science? E.g. does it include citizens in the scientific process? • Is the scientific objective generally apt for citizen science and why? • Does the scientific objective show relevance for society and does it address a socially relevant problem? • Are the scientific goals sufficiently clear and authentic? • What are the scientific gains of the project and how are these defined?
	Data and Systems	
	Ethics, data protection, IPR	• Does the project have a data management plan, IPR strategy and ethical guidelines? • Is the data handling process transparent? E.g. do citizens know what the data is used for, where the data is stored and shared? • Are data ownership and access rights clear and transparent? How is the publication of data handled?
	Openness, standards, interfaces	• Does the project have open interfaces to connect to other systems and platforms? • Is the generated data shared publicly and under which conditions, e.g. anonymized, metadata, ownership, consent, etc.?
	Evaluation and adaptation	

<table>
<tr><td rowspan="11"></td><td>Evaluation and validation of data</td><td>• Does the project have a sound evaluation concept, considering scientific as well as societal outcomes?
• Is evaluation planned at strategic points of the project?
• Does the validation of citizen science data match with the scientific question and the expertise in the project?
• Are indicators and evaluation methods defined? Are all stakeholders considered?
• What processes are defined to guarantee high data quality?</td></tr>
<tr><td>Adaptation of process</td><td>• Does the project include a scoping phase?
• Does the project have an appropriate risk management plan?
• Are project structures adaptive and reactive?
• Does the project include feedback loops for adaptation?</td></tr>
<tr><td colspan="2">Collaboration and synergies</td></tr>
<tr><td>Collaboration and synergies</td><td>• Does the project collaborate with other initiatives at national or international level to enhance mutual learning and adaptation?
• Does the project link to experts from other disciplines?
• Does the project build on existing citizen science expertise in the specific field of research?
• Are there plans for sustaining the collaboration between citizens and scientists?</td></tr>
<tr><td colspan="2">Outcome and impact</td></tr>
<tr><td colspan="2">Scientific Impact</td></tr>
<tr><td>Scientific knowledge and publications</td><td>• Does the project demonstrate an appropriate dissemination strategy?
• Are citizen scientists participating in publications or is their engagement recognized?
• Did the project contribute to adult education and life-long-learning?</td></tr>
<tr><td>New fields of research and research structures</td><td>• Did the project generate new research questions, new projects or proposals?
• Did any cross-fertilization of projects take place?
• Did the project contribute to any institutional or structural changes?</td></tr>
<tr><td>New knowledge resources</td><td>• Does the project ease the access to traditional and local knowledge resources?
• Does the project foster new collaborations amongst societal actors and groups?
• Does the project contribute to a mutual understanding of science and society?</td></tr>
<tr><td colspan="2" style="display:none"></td></tr>
<tr><td colspan="2" style="display:none"></td></tr>
<tr><td rowspan="3">Citizen scientist dimension</td><td colspan="2">Process and Feasibility</td></tr>
<tr><td colspan="2">Involvement and support</td></tr>
<tr><td>Target group alignment</td><td>• Does the project have specific communication plans for target groups?
• What engagement strategies does the project have (e.g. gamification)?
• Are the options for participation and the degree of involvement diversified?</td></tr>
</table>

	Degree of intensity	• In which project phases are citizens involved? • Are citizens and scientists equal partners in the knowledge generation process?
	Facilitation and communication	• Are support and training measures adapted to the different participant groups? • Are objectives and results clearly and transparently communicated? • How interactive is communication and collaboration between scientists and citizens organised?
	Collaboration and synergies	• Does the project involve organizations that provide of relations and communication structures with citizens?
	Outcome and impact	
	Individual development	
	Knowledge, skills, competences	• What are the specific goals to be achieved by the participants? • What are the learning outcomes for the individuals? • Do individuals gain new knowledge, skills and competences? • Does the project contribute to a better understanding of science?
	Attitudes and values	• Does the project influence the values and attitudes of participants regarding science?
	Behavior and ownership	• How much involvement and responsibility is offered to the participants? • Does the project foster ownership amongst participants? • Does the project contribute to personal change in behavior?
	Motivation and engagement	• Does the project raise motivation and self-esteem amongst participants? • Are participants motivated to continue the project or involve in similar activities? • In case of younger students, do they consider a scientific career?
Socio-ecological/ economic dimension	***Process and Feasibility***	
	Dissemination & Communication	
	Target group and context alignment	• Does the project have a targeted outreach and communication strategy? • Does the project include innovative means of science communication and popular media (e.g. art)?
	Active involvement, bi-directional communication	• Does the communication strategy include hands-on experiences and bi-directional communication? • Is the engagement strategy clearly communicated and transparent? • Are the project objectives and results clearly and transparently communicated?

	Collaboration and synergies	• Does the project seek collaboration with science communication professionals? • Does the project leverage civic society organizations for communication and synergies?
	Outcome and impact	
	Societal impact	
	Collective capacity, social capital	• What are the societal goals of the project and how are they communicated? • Does the project foster resilience and collective capacity for learning and adaptation? • Does the project foster social capital?
	Political participation	• Does the project stimulate political participation? • Does the project have any impact on political decisions?
	Ecological impact	
	Targeted interventions, control function	• Does the project include objectives that protect and enhance natural resources? • Does the project contribute to higher awareness and responsibility for the natural environment?
	Wider innovation potential	
	New technologies	• Does the project foster the use of new technologies? • Does the project contribute to the development of new technologies?
	Sustainability, social innovation practice	• Does the project have a sustainability plan? • Are the project results transferable and to what extent? • Does the project contribute to social innovation?
	Economic potential, market opportunities	• Does the project have any economic potential to be exploited in the future? • Does the project include any competitive advantage? • Does the project have any cooperation for exploitation, e.g. with social entrepreneurs? • Does the project generate any economic impact, e.g. cost reduction, new job creation, new business model, etc.?

4. Outcomes from the Review Process and Discussion of the Criteria Catalogue

The presented framework touches upon the most relevant aspects of citizen science. As an open framework it also allows for projects to expand and adapt according to their specific project structures. Adding the citizen dimension on an equal level next to the scientific and socio-ecological/economic dimension indicates an expansion of focus from more traditional scientific projects. Empowerment of citizenship and enabling of critical participation stands on equal terms with scientific objectives, triggering a need for new research designs (Sieber and Haklay 2015). Questioning the collective capacity and resilience of society to provide evidence of societal impact relates to current theories of citizen participation, collective intentionality and crowdsourcing. While the concept of crowdsourcing builds on the principle of abundance of contributors, observers and collectors (Haklay 2013), questioning its impact on individual and community level adds a quality dimension to it.

Key decisions for the framework implementation relate to choice of target groups and process. It is important to differentiate whether the project evaluation will be performed by project members themselves, by funding agencies, external experts or as a collaborative effort. Importantly, the efforts related to evaluation should not be underestimated and included in time and resource budgeting. Gathering evidence on the various levels of evaluation is resource intensive and projects should seek for a balanced approach in terms of measures and expected outcomes.

If funding organizations plan to apply such a catalogue of evaluation criteria, the definitions of citizen science (see our discussion above) and expectations towards it need to be clearly communicated (Eitzel et al. 2017). Support measures, including specific evaluation guidelines and methods for proper evaluation, will need to be developed, and can build on guidance developed by e.g. Pocock et al. (2014) and Pettibone et al. (2016) and the evaluation criteria framework presented in this paper.

The comprehensiveness of the framework implies that its application needs specific tailoring and contextualization according to spatial, temporal and socio-economic demands of the project or program. Criteria need to be prioritized for individual projects or initiatives. While all main criteria in the framework should be rated, they may receive different weightings as projects cannot always fulfill all to the same degree. While a certain project might aspire social goals and succeed in creating societal impact it might not open new research fields or have little economic potential. Therefore, a tailored selection of supporting questions is needed. Projects and programs will place different emphasis on certain aspects and thereby occupy different spaces across the range of criteria proposed. Citizen science projects are unlikely to reach an exemplary high standard across all the criteria proposed. Here, a visualization of the application criteria might be an approach to help in showing the strengths of each project.

To operationalize evaluation, the prioritization of indicators should be aligned with the project and program objectives and needs to take place before applying the evaluation framework. The prioritization of criteria should be in the hands of the respective project drivers; e.g. civil society organizations might focus more on the socio-ecological/economic dimension, while research funding agencies might put stronger emphasis on scientific results. Nevertheless, the comprehensiveness of the catalogue along the three dimensions shows where science, society and individual participants can benefit from the full potential of the science-society collaboration at equal footing. Synergies and trade-offs will need to be considered, and an initial clear set of criteria and evaluative scales adds transparency to the whole process. Recording and monitoring of project experiences along this criteria framework is required to evaluate and demonstrate good practice examples that may inform the development of successful citizen science.

A challenge is now to make the framework open for everyone, applicable to different types of projects and different programs. Ideally, the framework should be reviewed and amended by feedback from the community and evolve over time. At the same time this could be an opportunity for the emerging citizen science associations in Europe (ECSA), the US (CSA) and Australia (ACSA), to provide added value to projects and funding agencies by offering support in implementing adequate evaluation structures and exchange of practice.

Finally, just as this framework should be improved over time by the growing experience and reflection from the community, the same adaptive capacity and openness is requested from project evaluation. While evaluation should be comprehensive it should not be static. In the course of a citizen science project, which often runs over various years, the framework should allow for reflecting developments and contextual changes in the projects. In addition, long-term monitoring of the selected criteria is necessary in order to capture the project's far-reaching impact.

5. Conclusions

The presented approach towards a citizen science evaluation framework integrates three assessment dimensions, i.e. scientific advancement, citizen engagement, and socio-ecological/economic impact. The evaluation criteria matrix with ten main criteria and its supporting catalogue of questions can be applied for different purposes. For funding agencies, for instance, it can inform the development of selection and evaluation criteria for citizen science initiatives, as it has already taken place in Austria. For citizen science projects the question catalogue can support the holistic reflection about project strengths and weaknesses, as well as potentials for improvement – during project planning but also as a tool for adaptive project management and impact assessment. For scientific organizations, the consideration of the three equally footed dimensions, might enrich reflections about citizen's engagement and impact for socio-ecological systems. For civil society organizations taking a closer look at the scientific perspective might raise options on how to better exploit benefits from the collaboration with science. Thus the evaluation framework can be used as (a) a planning instrument for designing projects in the making, (b) a mid-term and final self-evaluation for projects, and c) an external evaluation for funding agencies.

For further development the presented criteria framework will now need to be transformed into a practical assessment tool for projects and initiatives, i.e. through a mix of qualitative and quantitative methods, such as tailored online surveys, usage statistics, in-depth interviews or focus groups. It can assist them in their strategic planning, monitoring and impact assessment. Follow-up work will apply the evaluation framework to a set of projects and offer these examples for wider reflection. Given the interest expressed by funding agencies, citizen science representatives and national citizen science communities, such as in Austria and Germany, we see a need and opportunity to develop the framework into tailored practical tools. We hope, these assessment criteria will fuel and trigger further discussion on measures of success and evaluation for different project approaches and different contextual settings within the wider citizen science community. Overall, a proper evaluation framework will help to professionalize the citizen science community, will foster and guide targeted funding support, and will ultimately increase the desired impact of citizen science in science and society.

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