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Learning Opportunities and Outcomes in Citizen Science: A Heuristic Model for Design and Evaluation

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LEARNING OPPORTUNITIES AND OUTCOMES IN CITIZEN SCIENCE: A HEURISTIC MODEL FOR DESIGN AND EVALUATION

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Growing numbers of Citizen Science (CS) projects focus on learning about science through the collaboration of professional scientists and citizen scientists. However, resources for the design and evaluation of CS projects in terms of learning about science are scarce. Therefore, this chapter aims to provide a model for the heuristic analysis of the supply and use of learning opportunities in CS and apply it to different CS projects. We hope that the design of future CS projects considers the MODEL-CS as an approach to enable as many participants with different prerequisites as possible to take advantage of the learning opportunities provided.

Keywords: Environment, Research cooperation frameworks, Non-formal Learning

1 A MODEL FOR DESIGN AND EVALUATION OF LEARNING IN CS

This chapter aims to provide evidence for promoting science learning in Citizen Science (CS) projects which focus on education. In CS projects, citizens engage with professional scientists in scientific inquiries not only to push forward scientific endeavours but also to learn about science (Wals, Brody, Dillon, & Stevenson, 2014). Therefore, CS projects provide opportunities to learn in informal settings (National Academies of Sciences, Engineering, and Medicine [NASEM], 2018). However, research on learning in CS remains under-theorised (Crain, Cooper, & Dickinson, 2014), mainly for three reasons:

First, initiators of CS projects often lack capacities for designing learning opportunities and evaluating individual learning outcomes (Bonney, Phillips, Ballard, & Enck, 2016). Although CS projects provide informal settings for citizens to learn about science, only 7% of CS projects explicitly focus on education and those mainly on formal settings (Follett & Strezov, 2015). Hence, what citizens learn while participating is rarely the focus of most CS projects. Considering educational outcomes as one of the projects' goals, when planning a CS project, has the potential to improve the intentional design of learning opportunities (NASEM, 2018).

Second, the degree of participation in CS ranges from contribution (i.e. citizens contribute only to data collection) to co-creation (i.e. citizens participate in setting up the research; Shirk et al., 2012). Different degrees of opportunities to participate in scientific activities may impact the available learning opportunities. For example, project designers should ask themselves, if scientific reasoning skills of participants increase by just processing data in contributory CS projects (Jordan, Crall, Gray, Phillips, & Mellor, 2015). Furthermore, project designers need to consider how participants use these opportunities based on their assumed role, motivation, etc. and how it affects what they learn from participation (Phillips et al., 2019).

Third, the constructs to be addressed by learning in CS are not clearly defined, and corresponding assessment tools are scarce (Bonney et al., 2016). Designing opportunities for learning requires to define the constructs addressed (i.e. intentional design). Collaborations of scientists and other initiators of CS projects with science educators might help to address the challenges of intentional design for learning in CS projects.

In our collaborative attempt of natural scientists, science educators and psychologists to evaluate knowledge transfer in CS (WTimpact project), we developed a model to inform deliberate design and evaluation of learning in CS. The Model for the Design and Evaluation of Learning in CS projects (MODEL-CS; Figure 1) follows the framework for public participation in scientific research (Shirk et al., 2012) and integrates a supply-use model on the conditions of learning (Brühwiler & Blatchford, 2011). According to the MODEL-CS, prerequisites of professional and citizen scientists must be accounted for the supply and use of learning opportunities in CS projects. Furthermore, the supply of learning opportunities (e.g. inquiry activities) results in differing use (e.g. participation levels), which can be observed and measured. The resulting data output and the way how it is accessed by citizen and professional scientists influence the scientific as well as individual learning outcomes (e.g. in terms of knowledge development). In a feedback loop, the outcomes also affect citizen and professional scientists in that they result in changes at the individual, project or community level (Shirk et al., 2012).

This model now serves as a heuristic tool for the presentation and analysis of different CS projects. In the following, we illustrate how the MODEL-CS tackles the challenges mentioned above of designing and evaluating CS projects for learning about science. We will show how the model covers the design of learning opportunities and their use during participation as well as learning outcomes after participation. We will present three research projects about learning in CS and how they can be situated within the MODEL-CS.
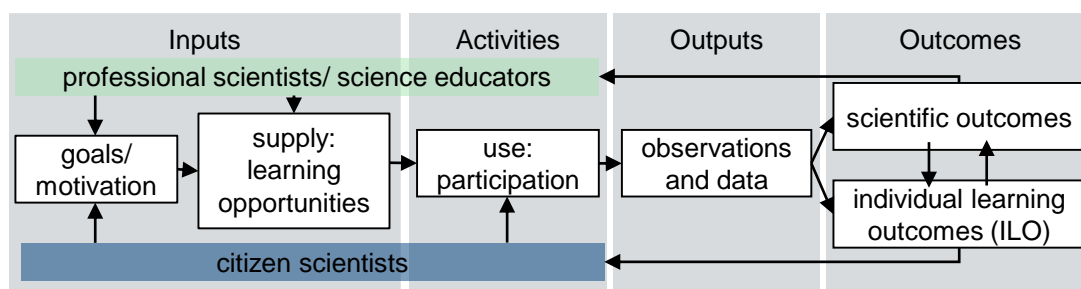

Figure 1. Model for Design and Evaluation of Learning in Citizen Science (MODEL-CS; Logic Model of PPSR; Shirk et al., 2012; Supply-Use Model; Brühwiler & Blatchford, 2011).

2 YOUTH PARTICIPATION IN MUSEUM-LED CITIZEN SCIENCE PROGRAMMES

Natural history museum (NHM)-led CS provides a useful context in which to study learning outcomes and project design because both NHMs and CS share the dual goals of scientific research and science education (Ballard et al., 2017). NHM-led CS projects also provide the opportunity to systematically examine the specific nature of the learning settings (supply of learning opportunities) and the activities young people engage in (use of learning opportunities) when participating. The LEARN CitSci project, therefore, studies these two aspects of projects involving youth led by three NHMs (two in California; one in London) across two field-based settings (short-term BioBlitz events and ongoing monitoring projects focused on seaweed, backyard wildlife, or insects) and two online CS platforms (iNaturalist and Zooniverse).

2.1 Methods and Participants

To explore and characterise young people's participation and learning settings, we draw on Cultural Historical Activity Theory (CHAT; Engeström, 2001) and use Environmental Science Agency (ESA) as our research and analytical framework (Ballard, Dixon, & Harris, 2017).

2.1.1 Field-based settings

We relied upon ethnographic field observations to capture data about the participation of over 120 young people (5–19 years), in one ongoing field-based CS project (young people attending at least three sessions) and 3–5 short-term events (BioBlitzes) for each NHM. We developed observation protocols to focus on the features of each setting. Influenced by CHAT, we documented setting features in categories, e.g. tools, rules, division of labour, community setting, object (goals) and interactions with people. An iterative process of analysing field notes, including memo writing and qualitative data analysis using structural and thematic coding aimed to (a) identify types of participation and match them to ESA components, (b) identify and categorise setting features that open up or shut down ESA learning opportunities.

2.1.2 Online/ technology-enhanced programmes

To capture participation of young people in online CS programmes and identify the supply of learning opportunities, we analysed the technological affordances of tools on the Zooniverse and iNaturalist platforms and extracted log files from both platforms for 104 Zooniverse and 115 iNaturalist users. The participants were recruited through existing museum contacts, project activities run by the museums, and advertisement via Zooniverse.

2.2 Findings

2.2.1 Field-based settings

In about 80% of the observations, we saw evidence of young people engaging in scientific practices and opportunities to develop ESA. However, among those episodes in which participation in CS seemed to open up learning opportunities for ESA, we found important patterns in the ways that the CS contexts supplied opportunities for young people to develop and identify their own expertise in a scientific practice, as well as opportunities for constructive interactions around science with facilitators; specifically in short-term events (BioBlitz). We also saw a large proportion of episodes in which a setting feature had the potential to open up learning opportunities for ESA, but had to be characterised as "missed opportunities". These

often centred around the design or framing of a programme that did not focus on, or sometimes did not even mention, the contribution to authentic scientific research of the CS activity.

2.2.2 Online/ technology-enhanced programmes

It could be argued that the two platforms afford a range of learning opportunities (e.g. observing, identifying and classifying wildlife or museum specimens), yet they differ substantially. iNaturalist acts as a social network site. Users' contributions and profiles are open to the public. The online community and machine learning techniques scaffold the process of identification. In Zooniverse, however, only scientists set up projects and have access to users' contributions. Observations (data that have been collected) are provided only by scientists, as are tutorials about how to participate (Herodotou, Aristeidou, Miller, Ballard, & Robinson, 2020). Our analysis showed differences in participation profiles (Table 1) and participation itself (use of learning opportunities). Most iNaturalist participants make observations only (taking/uploading pictures), while only 19 (out of the 115) young people also identified observed species. The average number of contributions per user was 22. Yet, 11 participants had between 170 to 17,169 contributions.

Table 1: Participation profiles, based on activity ratio, relative activity duration, variation in periodicity, daily devoted time.

Profiles	Zooniverse (N = 104)	%	iNaturalist (iNat; N = 115)	%
Systematic	Users are active, visit the platform regularly	5	Linked to iNat for a long period, systematic visits but relatively low activity	29
Casual	Users have inconstant visits, not very active	8	N/A	—
Moderate	Users have constant visits, not linked to the platform for long, not very active	15	Not linked to iNat for a long period, relatively systematic visits, relatively low activity	8
Visiting	Users contributed to projects one or two days only, very active during these days	33	Users only active for 1–2 days	51
Lasting	Linked to Zooniverse the longest, but do not visit regularly, only a few active days	39	Linked to iNat for a long period, very few active days, no systematic participation	12

2.3 Discussion and Implications

Given the wide variety of settings and ways that young people participate in CS, our analysis of how participation and setting features may open up and shut down learning opportunities points to key design features that can inform the design of environmental CS programmes. Specifically, we found that the ways that facilitators framed the activities and positioned young people at CS events like BioBlitzes greatly influenced whether and how young people took on roles in CS practices. For online settings, our findings reveal that the affordances of each platform allow for different forms of participation, as evidenced in the different forms of user contributions. Furthermore, the participation profiles based on cluster analysis provide a starting point for understanding and scaffolding young people's engagement in informal science learning via online CS. While some types of participation we observed are unique to a specific setting, for some types we found equivalents across field-based and online settings, pointing out opportunities for joint efforts in developing design modifications across CS settings to improve the supply and use of learning opportunities.

3 The Design for Participation Affects Pupils' Engagement with Learning Opportunities

From 2007–2017, the Austrian Ministry of Research has run a funding scheme called "Sparkling Science" to promote research cooperation between scientists, pupils and their teachers (Austrian Agency for International Cooperation in Education and Research, n. D.). Sparkling Science projects are quite similar to CS projects. Equally, Sparkling Science projects asked pupils to participate in reasonable research tasks. Bonney and colleagues (2016) suggest that CS projects should rely less on the personal experience of participating scientists and teachers, but should include more objective evaluation methods. Within ten years, we have observed five Sparkling Science projects, which offer different scientific research goals and participants activities (Table 2). All projects included accompanying evaluation research to learn about pupils' learning outcomes. Now we analysed and compared our findings again to find out whether there are common patterns observable among all five projects. The goal is to inform future project designers which activities are more likely to foster pupils' engagement with the learning opportunities offered in CS projects.

Table 2. Analysis of five Sparkling Science Projects regarding (1) scientists' interests, (2) time span, (3) pupil participation, (4) pupil tasks, (5) schools and grades, and (6) evaluation research with pupils.

	Top Klima Science	Alien Invaders	GrassClim	Viel-Falter	Woody Woodpecker
(1)	Hydrologic balance and global change: prospect for mountain areas in the face of changes in land use and climate	Alien plants and their role in reconstructions of river banks	Interactive effects of changes in climate and management on the yield and carbon dioxide source/sink strength of grasslands	Development and evaluation of a monitoring system of settlement-related butterfly habitats	Wood anatomy analyses of conifers at the alpine timberline
(2)	2008–2010	2008–2010	2010–2012	2013–2016	2014–2017
(3)	2 years	2 years	2 years	1 year or 2 years	1 year or 0,5 year
(4)	Data collection outdoors; data analysis; workshops at school and university; social event; publish results in agricultural journal	Data collection outdoors; data analysis; workshops at school and university	Data collection outdoors; workshops at school	Data collection outdoors; workshops at school and university; social event	Data collection outdoors; data analysis; workshop at school, at university, social event
(5)	High school with a focus on agriculture, grade 9	High school, grade 9	High school with a focus on agriculture, grade 9	Primary schools, Middle schools, High school with a focus on economics, grade 3, 4, 7, 8 & 12	High school, grade 10-12
(6)	50 pre-post-test (OECD, 2005); 12 semi-structured interviews	45 pre-post-test (OECD, 2005); 12 semi-structured interviews	10 semi-structured interviews	117 pre-post-test (Wilde et al., 2009); 19 in-depth interviews	45 pre-post-test (Urhahne et al., 2007); 12 semi-structured interviews

3.1 Setting, Participants and Methods

All five Sparkling Science projects (Table 2) followed a predefined set of requirements for integrating pupils and their teachers in a given research process and offered opportunities for

pupils to participate in various research phases such as reflecting on hypothesis, collecting data and publishing results. It was expected that pupils develop an understanding of the scientific background of the project as well as how science works, e.g. what counts as high-quality data. Thus, emphasis was put on offering pupils a range of learning opportunities. As all projects conducted field research, pupils were able to work outdoors with scientists and accomplish research tasks independently, such as collecting, analysing and interpreting data. In addition, pupils participated in workshops at the university or their school and/or visited social events. All in all 267 pupils and more than 12 teachers participated in these five Sparkling Science projects. Earlier projects (Table 2) took theories on interest and motivation (e.g. Deci & Ryan, 1985) as a starting point to observe changes in pupil's interest and motivation to participate in these projects (e.g. Wilde, Brätz, Kovaleva, & Urhahne, 2009). Later projects added another focus and tried to observe the pupil's development in understanding the Nature of Science (Urhahne, Kremer, & Mayer, 2007). All projects included a content knowledge test on pupils' understanding of the scientific background. In addition, pupils participated in interviews during or at the end of the project (Table 2). In this study, we conducted a qualitative, comparative case study analysis (Flick, 2007) based on the evaluation reports published for each project.

3.2 Findings and Recommendation

The comparison of the projects' evaluation findings, especially those based on interviews with participating pupils (Table 2), reveals common patterns. All projects show a certain degree of incompatibility of research and everyday school life. Due to changing weather conditions, field research requires flexible planning whereas teachers need long term planning. Primary school teachers are more likely to adapt, whereas secondary and high school teachers may be more restricted. Students' situational enthusiasm does not always fit scientists' approach of persistent work, which follows a standard procedure. In terms of practical science activities, all pupils develop a better understanding of how scientific data is collected and that data quality is related to its accuracy and reliability. However, many pupils have difficulties in understanding the scientific background of the project and engaging in cognitive activities, such as reading and writing scientific protocols. These difficulties persist throughout the project duration. When working with younger children (age 6–15 years), it appears to be helpful to bridge the gap between pupils' needs and their role as researchers in the projects. In general, young pupils enjoy doing practical work or work outdoors. Teenagers are more likely to find research activities rather tedious. Educators who are experienced to work with a particular age group in out-of-school settings are more likely to meet children's needs (e.g. to make fun) than scientists or formal teachers. All pupils want to feel appreciated, valued and trusted for the work they contribute. Pupils expect researchers to be able to answer the research question at the end of the project and are disappointed if they do not learn about the results. The setting and/or expected research outcome should offer a direct link to pupils' personal life, e.g. to their local environment, or answer questions they value important for their own life. The duration of the project and the research activities should not last too long and should avoid repetitive tasks.

4 Learning outcomes in a CS biodiversity project

This CS project links biology education and environmental education in formal education. Research sites were private gardens, schoolyards and parks. Selected aims of the CS project

were: (a) to record biodiversity through target species groups with school students (occurrence of selected garden birds; selected butterflies' presence and activities); (b) and aspects of acquired knowledge. Educational goals were defined to increase students' knowledge of the selected species groups and habitat-species relationships, as well as raising awareness towards the importance of green spaces and gardens for biodiversity conservation. Following the supply-use logic model, we inquired learning outcomes for students. Within MODEL-CS, we looked at the effects on individual learning outcomes. In a previous study, we focussed on the perspective of student citizen scientists and concentrated on educational goals and learning outcomes focusing on the following four individual learning outcomes (ILO) categories: (1) Interest in Science and the Environment, (2) Self-Efficacy, (3) Motivation, (4) Knowledge of the Nature of Science (Phillips et al., 2018, p. 7). These four were applied in evaluation via questionnaires, partly pre and post, some ILOs only after the project (Kelemen-Finan, Scheuch, & Winter, 2018). Additionally, a new ILO was introduced to measure attitudes, which were important for the evaluation of the environmental educational aims. Exemplary results show a significant pre-post-rise in the scale 'nature garden' (pre: $N = 317$, Mdn = 10 [3–12]; post: $N = 256$, Mdn = 11 [3–12]; $p < .001$) with a medium to large effect size of 0.52 (Cohen's d). For the 'biodiversity' scale, the analysis also showed an increase, but with only small to medium effect size (Cohen's $d = 0.33$; Kelemen-Finan et al., 2018). In this study, the focus was the skills of students' species identification skills.

4.1 Methods and Participants

Over two years, 428 students from 27 school groups, supervised by 21 teachers, participated in this CS project. In total, 337 garden owners were interviewed with a standardised questionnaire, thereof, the students investigated 80 gardens and parks. Students used survey methods to monitor a set of common and easy-to-determine butterfly and bird species.

In addition to the questionnaires on the ILOs (see above), we tested the improvement of the students' species knowledge as a means to compare the students' perceived learning (i.e. scale 'self-efficacy') with the assessment of species identification rate as learning outcomes. In a quiz, students had to identify seven selected common bird species (four by picture; three by sound) and four common butterflies (pictures) at the closing event of the project. Overall, 186 students participated in this quiz. We compared the species knowledge of students who recorded target species (intervention group) to students who did not (comparison group). Birds were recorded by $n = 122$ students compared to $n = 64$ who did not, for butterfly activities the respective numbers were $n = 99$ for those who did record butterflies and $n = 87$ who did not.

4.2 Findings

Overall, the project improved students' knowledge of target species, and it raised attitudes towards the importance of man-made habitats such as gardens and parks for biodiversity conservation. With respect to species knowledge, the quiz showed that the correct species identification of the students who observed the respective species group were 10–25% higher compared to the group that did not work with the respective species group. For an overlook, see table 3, with visual identification being generally higher than auditive identification.

Table 3: Correct identification rates of the two groups.

Identification rate %	Recorded target species	Did not record target species
Bird Quiz Pic	81%	63%
Bird Quiz Sound	50%	35%
Butterfly Quiz	75%	60%
Overall	**70%**	**55%**

Overall, the recognition rate was highest for the Blue Tit (*Cyanistes caeruleus*, visually: 98% in both groups) and lowest for the Great Tit (*Parus major*, audio; both groups only about 10%). In general, bird song recognition was less successful (50% of students who recorded and 35% of students who did not record birds) than visual recognition (81% of students who recorded and 63% of students who did not record birds).

In the butterfly quiz, most students (95% for students who recorded vs. 69% for students who did not record butterflies) recognized the Swallowtail (*Papilio machaon*) correctly. Common but similar species within some families, such as Pieride (Common Brimstone, *Gonepteryx rhamni* vs. Small White, *Pieris rapae*) or Nymphalidae (Red Admiral, *Vanessa atalanta*, vs. various others) were commonly misidentified, but lesser so by students who had recorded them outdoors. Students who recorded and students who did not record butterflies differed by 4% more correct identifications for the Red Admiral and 26% for the Swallowtail.

4.3 Discussion and Implications

We could show with the birds' quiz that bird identification was satisfying in this CS project and therefore the results of the students reliable; this was not the case in some butterfly species. This aspect is crucial in CS projects to link the learning of the participants with ensuring data quality. Within the project, the science educators of the team did supply an activity with photos of birds and butterflies in a workshop for the students to help them learn the identification. The photos were selected to show the natural range of "good and bad" views on the target species (e.g. difference in illumination to show birds in full light and within treetops in green light). The selection can be an example of a purposefully designed learning opportunity, to support citizen scientists as well as enhancing data quality. The identification workshop did work for visual bird identification but not so well in some butterflies' cases, auditive identification training did not take place.

Therefore, models like the combined and logic model (Brühwiler & Blatchford, 2011; Shirk et al., 2012), or the checklist with ILOs of Philipps and colleagues (2018) are very helpful to link CS projects with educational aims and learning activities. Taking the MODEL-CS as a heuristic framework to think about motivation and goals of citizen scientists (Figure 1), we learned that students and teachers have different expectations and this has to be considered and to be negotiated with those of the scientists, even in contributory CS projects. This project can serve as an example that efforts to undertake evaluation on different individual learning outcomes with a focus on the students and the teachers (e.g. Scheuch et al., 2018) help to further develop CS as a meaningful way of learning in science and environmental education (Wals et al. 2014).

5 Summary Discussion and Conclusions

In this chapter, we provided MODEL-CS as a heuristic tool for connecting the analysis of learning in different CS projects to the logic of CS project design (Shirk et al., 2012). We extended it by accounting for participants' prerequisites and differentiating between the supply and the use of learning opportunities (Brühwiler & Blatchford, 2011). From the analysis of different CS projects in this chapter, the following components seem essential: (a) prerequisites (i.e. goals, interests, motivation, previous knowledge and skills), (b) supply of learning opportunities (i.e. design features), (c) use of learning opportunities (i.e. differences in participation) and (d) individual learning outcomes (i.e. aligned with goals, embedded in activities). Furthermore, the heuristic analysis with MODEL-CS facilitated the identification of interactions between prerequisites and the supply as well as the use of learning opportunities.

When designing and evaluating CS projects for learning, it has to be kept in mind that the interactions between the different goals, the supply and actual use of learning opportunities affect both, the scientific and individual learning outcomes. For the studies reported here, it was especially important to (1) coordinate prerequisites of citizen scientists and professional scientists for the design of learning opportunities, (2) to consider how different activities afford learning opportunities and (3) to embed the assessment of ILOs into the project activities. For example, the professional scientists' goal of acquiring a standardised data collection did not fit to students' situational enthusiasm and hence, resulted in the use of learning opportunities that differed from the standard procedure. This mismatch illustrates how coordinating professional scientists' goals and citizen scientists' prerequisites could inform and improve the design of learning opportunities, a demand for science educators as facilitators in CS projects.

The purpose of MODEL-CS is to provide a model that facilitates new insight into the design and evaluation of CS projects for learning. More specifically, applying MODEL-CS as a heuristic tool to different CS projects with a focus on education could highlight the interactions of participants' prerequisites with the supply and the use of learning opportunities. We hope that MODEL-CS can support the future design of CS projects by considering participants' prerequisites to improve the learning opportunities provided and increase their use.

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