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Deconstructing citizen science: a framework on communication and interaction using the concept of roles

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Abstract

Citizen science opens the scientific knowledge production process to societal actors. In this novel collaboration process, scientists and citizens alike face the challenge of new tasks and functions, eventually resulting in changing roles. Role theory provides a way of conceptualizing the roles that people take in communication and interaction. We use role theory to create a framework that identifies scientists' and citizens' tasks in citizen science projects, main aims of communication, spaces they interact in, and their roles — thus providing a structured way to capture communication and interaction in and about CS for further scientific reflection and practical application.

Keywords

Citizen science; Science communication: theory and models

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Communication and interactions in citizen science

Foundations

Citizen science (CS) projects provide a wide range of opportunities for engagement between members of the public and scientists [Haklay, 2013; Shirk et al., 2012]. Wiggins and Crowston [2015, p. 1] emphasise this collaboration in their definition of CS as "a form of research collaboration that involves volunteers in producing authentic scientific research". Further, CS changes the communication and interaction between actors: as the roles of lay people and experts in knowledge production and use change [Bonfadelli et al., 2017; Turnhout et al., 2013], new modes of communication appear.

The term CS originated from two different epistemological directions: those by Irwin [1995] and Bonney [1996]. While Irwin defines CS as an approach to support democratic and participatory science, and focuses on the active citizens who work collaboratively with scientists to create knowledge, Bonney describes it mainly as a tool used by professional scientists where volunteering citizens contribute to

science through environmental data collection. In this paper, we make use of both CS definition strands.

While science and society have historically been seen as separate entities [Burns and Medvecky, 2018], the boundaries between scientific and civic actors begin to blur in CS. Here, members of the public are neither an external audience for communication, nor actors of scholarly communication within the academic community, but rather part of the project itself. Thus, CS differs from engaging the public in events like a science festival or edutaining formats such as science slams where the public is still seen as an external audience.

Communication and interaction processes in CS are a key element for the collaboration process between scientists and project participants, and are inseparable from the scientific activities. While communication to external audiences might be an addition to the science activities in research projects without public engagement, completely abstaining from outreach activities would not necessarily put the scientific endeavour at any risk. In contrast, both communication to external as well as project-internal audiences must be effective to enable scientific activities in CS [Riesch, Potter and Davies, 2013], for example by attracting participants and exchanging knowledge between project partners to fulfil the various project tasks.

Communication in CS may refer to two different meanings: communication as a process and as a tool. As a process, communication builds a joint understanding between actors of the reality of their collaboration. Thus, in a fundamental sense, communication encompasses interaction and collaboration, dialogue and reciprocal understanding, and negotiations [van der Sanden and Meijman, 2008]. In an expedient sense, strategic use of communication as a tool is used to convey the exchange of information; for example, to reach a target audience, to motivate participants' discussion of methods and data collection, to negotiate interests and motivation, to provide feedback, or to communicate results [e.g., Davis et al., 2018].

The actors in CS are members of different communities, namely the professional scientific and the non-professional, and they collaborate and interact to various degrees depending on the project. To achieve this, they must reach a degree of mutual understanding, which might be a complex process as both parties live and act within their own cultures, as described in Caplan's "Two-Communities Theory" [Caplan, 1979]: sometimes, differing logics and aims define these cultures, and thus understandings and perceptions may differ, including expectations, languages and jargon, value systems, motivations, and aims for research and participation.

A CS project that illustrates the aforementioned challenge was the Chicago Area Pollinator Study. The goals of this project were to promote wildlife-friendly behaviour changes, improve participants' attitudes towards pollinators, and increase knowledge about bees, urban habitats, and science [Druschke and Seltzer, 2012]. Unfortunately, the design dynamic was more instructive than collaborative, and while participants did learn more statistically, it was not much of an actual improvement. Interest was not improved either. According to the authors, the failure was because they neglected to truly bring citizen scientists into the whole collaborative effort. The authors attribute this failure to focusing too much on the data they could get from participants instead of focusing on and handling

participants' needs and expectations which resulted in miscommunication. Other CS project coordinators also report this challenge [e.g. Ramirez-Andreotta et al., 2015]. In their recommendations for other CS projects, Druschke and Seltzer [2012] emphasise the necessity to consider participants' views and needs and also to maintain active communication and exchange between scientists and participants.

Role theory

According to role theory, an individual has various roles in life that come with expectations on how to behave and this is associated with a particular social status [Linton, 1936; Miebach, 2010; van der Horst, 2016]. Role theory is not restricted to specific research fields and is applied in, for example, political sciences [Klose, 2019], the processes of identity construction in business [Simpson and Carroll, 2008], and sex/gender or family research or international relations [van der Horst, 2016].

Role theory, as a way of conceptualizing the roles that people take in communication and interactions, offers a useful structure for capturing the complex interactions in CS. This can be explained by two main strands of role concept that are relevant for our considerations: interactionist role theory and normative-structural role concept. The former, interactionist role theory, considers role to be a manifestation of reciprocal interactions with others [Turner, 1985]. As such, role is seen not as a fixed concept or set of norms and expectations by society, but as flexible, adopted, and acted out through individuals in dynamic social processes [van der Horst, 2016; Yodanis, 2003] and is therefore only temporary [Krappmann, 1971].

In the latter, normative-structural role concept, an individual's role is defined by their position or function in social order, such as profession or membership, which is linked to certain rights and privileges, duties, and obligations. Roles come with specific rules for interactions [Linton, 1936; Merton, 1957; Miebach, 2010] and role actors are expected to more or less abide by them in given situations [Mead, 1934] in order to support and structure the social culture [Lynch, 2007]. Additionally, within the normative-structural role concept, the status of these actors in the social order is linked to their position on the ladder of appreciation and prestige in society [Dahrendorf, 2010].

In CS, new modes of communication and interaction emerge at the micro and meso level, due to a change in the relationship and roles of actors. The micro level refers to interactions of individuals and their roles on a small scale like in a CS initiative. The meso level considers groups of actors and their communication and interaction and how roles change at a structural level. For example, at the micro level, actors might take up roles that had previously not been open or routine to them: members of the public may become project initiators, and scientists may become motivators for participation. On the meso-level, traditional role concepts are challenged, as previously the public had a more passive, receiving role as the audience [Loosen and Schmidt, 2012; Neuberger et al., 2019]. Now, the public assumes a performance role in the knowledge production process, while the scientists' role might have shifted from that of a knowledge producer to facilitator [Neuberger et al., 2019]. Engaging with members of society in the research process

also means allowing for new questions and different forms of knowledge to be included, which may result in the questioning of science's privileged status and sovereignty over public knowledge.

The new or shifting roles in CS have resulted in novel interaction and communication processes between actors for which there is very little research. Science communication research has responded to this by shifting to a conceptual and overarching perspective when looking at CS [Lewenstein, 2016]. However, while the literature on CS practice and outcomes is increasing exponentially [Kullenberg and Kasperowski, 2016; Meyer and Sandøe, 2012], analyses of the actual nature of communication and interaction processes among actors in CS is scarce. In order to change the perception of science communication as a unidirectional dynamic, communication research on CS should focus more on actors' new or shifting roles in CS.

In this paper, we contribute to the understanding of communication and interaction processes in CS by (1) providing a conceptual framework of CS communication and interaction processes and roles, (2) adapting the concept of role theory to roles in CS and by (3) exploring the interactions and roles at the micro and meso level, and the interaction space that CS creates for actors.

Framework on citizen science communication and interaction

The aim of this framework is to distinguish between different aspects of interlinked CS communication processes and interactions. These aspects include for example, the involvement of actors, communication aims, and potential roles related to the micro and meso-level. This framework can be useful, firstly, in stimulating scientific discussion and reflection on understanding and interpretation of communication, interaction, and roles in CS projects. Secondly, to develop concrete measures of communication by identifying tasks and responsibilities according to project aims. The framework thus also targets CS project coordinators and science communication practitioners.

The main purpose of the framework on communication and interaction presented in this section is to structure the challenges and potential benefits that might result from scientists and the participating public having a different understanding of involvement, tasks or roles.

Based on a classification of CS projects, we conceptualise our framework on CS communication and interaction processes as the combination of aspects at the micro and meso-level of CS.

The factors of this framework are deviated from citizen science scholarly literature and subsequently complemented by factors that relate to role theory. They address basic questions: what type of citizen science project is it? Who is involved? What is the involvement and which tasks do the actors have? These factors are the basis for Shirk's et al. [2012] categorisation of CS projects — whereby we explicitly address the factor of different actors involved where Shirk et al. and other scholars solely reflect on citizen scientists and their involvement in projects. The factor of main aims of communication is included as it implicates main underlying, explicit or non-explicit drivers for communication and interaction. The factors of interaction space and potential role are taken from role theory as relevant main categories.

Scholarly literature from the field of citizen science supports the framework's factors. In addition, we have applied a strand of theory not previously considered, namely role theory. The literature search was done to the point of theoretical saturation, i.e. until adding additional data didn't contribute any more properties to our categories.

CS project type and actors involved

CS projects are complex and have multiple layers such as research area, involvement, project targets, and expected outcomes [Bonney et al., 2016], and a single framework cannot express them all. As such, we have narrowed the framework to include only those, which are relevant for our purposes.

Communication and interaction in CS varies according to the degree of collaboration in any given CS initiative [Wagenknecht et al., 2021]. To better assess the different levels of engagement, Shirk et al. [2012] have proposed a framework for CS projects focussing on participants' levels of involvement, which we apply as the basic category to our framework.

Shirk et al. [2012] introduced three main project types which are: a) contributory projects, "which are generally designed by scientists and for which members of the public primarily contribute data", b) collaborative projects, "which are generally designed by scientists and for which members of the public contribute data but also help to refine project design, analyse data, and/or disseminate findings", and c) co-created projects, "which are designed by scientists and members of the public working together and for which at least some of the public participants are actively involved in most or all aspects of the research process" [Shirk et al., 2012]. We add the additional category of d) community-led projects where community members reach out to scientists with an issue of mostly local concern to the community and are the main drivers in the CS research process [Haklay, 2015; Roy et al., 2012; Shirk et al., 2012]. These projects have gained increasingly more attention in CS and add to the spectrum of levels of engagement (Table 1, column 1).

Whereas CS project type overviews often focus on citizens, our framework goes further by considering scientists as actors (column 2). This addition allows us to examine the scientist-citizen interaction, namely, the level of involvement and tasks of the two groups of actors (column 3), and the main aims of communication (column 4). These categories are related to the project level, which is the micro-level of CS.

We acknowledge that many different stakeholders play a role in CS projects. For example educators, communicators, community managers, societal organisations, policy makers, and (local) government. All of these actors might be considered when expanding the framework, however to lay the foundation of a basic understanding, we limit our scope to the two core actor groups of CS initiatives.

We apply role theory on the meso level and include the categories of 'interaction space' (column 5) and 'potential roles' (column 6) to allow for reflections on a more abstract level.

		Micro level of communication & interaction processes		Meso level of communication & interaction processes	
Citizen science project type	**Actors involved**	**Involvement and tasks**	**Main aims of communication**	**Interaction space**	**Potential role**
Contributory projects	citizen scientist/ member of the public	asked by scientists to collect and contribute data and/or samples; collect samples and/or record data; analyse data (sometimes); disseminate conclusions/ translate results into action (sometimes) (Shirk et al., 2012)	adopt and follow instructions, learn and apply (Tweddle et al., 2012, e.g. Kampen et al., 2015, Scheliga et al., 2018, Land-Zandstra et al., 2016)	decision-making and control mainly with scientist	contributor
	scientist	generally design project (Shirk et al. 2012) define research question(s), manage the project, implement research design, analyse data, disseminate findings, attract, manage and retain volunteers	provide information; promote participation; give instructions; provide feedback; motivate; inspire; maintain participation; educate; disseminate results (de Vries et al., 2019, Metcalfe, 2019, e.g. Brouwer and Hessels, 2019, Land-Zandstra et al., 2016)		knowledge creator; process manager; reflective scientist
Collaborative projects	citizen scientist/ member of the public	assist scientists in developing a study and collecting and analysing data for shared research goals; design data collection methodologies (sometimes); collect samples and/or record data; analyse samples; analyse data; interpret data and draw conclusions (sometimes); disseminate conclusions/ translate results into action (sometimes) (Shirk et al., 2012)	follow instructions; provide expertise and knowledge; disseminate results (e.g. de Vries et al., 2019, Rotman et al., 2014)	decision-making and control mainly with scientist with limited contribution by citizen scientists	contributor; knowledge provider
	scientist	generally design project (Shirk et al. 2012) define research question(s), manage the project, analyse data, disseminate findings, manage and retain volunteers, manage communication and exchange process	exchange information; promote participation; give instructions; provide feedback; provide training; motivate; inspire; maintain participation; educate; disseminate results (e.g. de Vries et al., 2019, Druschke and Seltzer, 2012, Metcalfe, 2019)		knowledge broker; process manager; reflective scientist

		Micro level of communication & interaction processes		Meso level of communication & interaction processes	
Citizen science project type	**Actors involved**	**Involvement and tasks**	**Main aims of communication**	**Interaction space**	**Potential role**
Co-Created projects	citizen scientist/ member of the public	project designed by scientists and members of the public working together; develop a study and work with input from scientists to address a question of interest or an issue of concern; choose or define question (s) for study; gather information and resources; develop explanations (hypotheses); design data collection methodologies (sometimes); collect samples and/or record data; analyse samples; analyse data; interpret data and draw conclusions; disseminate conclusions/ translate results into action; discuss results and ask new questions (Shirk et al., 2012) define research question(s) at least some of the public participants are actively involved in most or all aspects of the research process	negotiate interests; provide expertise and knowledge; exchange information, ideas and opinions; collaborate; create something together; listen to partners; agree on process; disseminate results and findings; provide feedback; create knowledge; advocate (e.g. Stepenuck and Genskow, 2018, Ramirez-Andreotta et al., 2015)	decision-making and control to be shared between scientist and citizen scientists	knowledge creator; advocate; advisor
	scientist	designed by scientists and members of the public working together (Shirk et al., 2012) define research question(s)	negotiate interests; provide expertise and knowledge; exchange information, ideas and opinions; collaborate; create something together; listen to partners; agree on process; disseminate results and findings; provide feedback; create knowledge; advocate; manage conflicts (e.g. Metcalfe, 2019, Stepenuck and Genskow, 2018)		process facilitator; change agent; self-reflexive scientist
Community-led projects	citizen scientist/ member of the public	aask scientists to conduct a scientific investigation and report on results; choose or define question (s) for study; gather information and resources (sometimes); interpret data and draw conclusions (sometimes); disseminate conclusions/ translate results into action (sometimes); discuss results and ask new questions (Shirk et al., 2012) define research question(s), communities conduct research independently or with little involvement of institutionalised science and/or professionals	follow own interests; involve community knowledge; exchange information, ideas and opinions; explain concerns, project etc; develop process; communicate results and findings; create knowledge (e.g. Hoover, 2016, Danielsen et al., 2018, Haklay and Eleta, 2019)	decision-making and control mainly with community members	process initiator; process manager; knowledge creator
	scientist	contribute knowledge; provide support and/or advice	adopt and follow requests, provide scientific knowledge to community concerns (e.g. Hoover, 2016, Haklay and Eleta, 2019)		contributor; advisor

Table 1. Framework on citizen science communication and interaction.

Micro-level communication and interaction

Involvement and tasks

Actors in CS are involved at varying degrees and with different tasks, which can be associated with different roles at the project level (Table 1, column 3 and 6). For example, the tasks and role of project manager, of data provider and analyst or the role of researcher and communicator must be defined and negotiated where necessary according to the project design, goals, and the level of actor involvement. It is important to emphasize that expectations of the role actors are vital in this context.

In ideal project management, the individual best able to perform a particular function and task would fill the pertinent role. The range of tasks is manifold in CS projects and is defined by the individual project design and management. Therefore, in CS research, it is important to recognise what skills are needed to fulfil a task such as data collection; does a citizen already possess the necessary skills, or could they be trained to acquire them? Whose responsibility is data quality management in a CS project? For example, the person collecting and providing data in a contributory project will need to fulfil certain standards and follow a protocol, and this may or may not require certain skills and expertise, but it certainly requires the physical ability to handle the task. The main qualification to fulfil a task therefore depends on the competencies and abilities a role actor has rather than their institutional educational or societal status.

Main aims of communication and interaction

Aims of communication are linked to the motivations and goals of communication actors in CS. Participants' main aims of communication might change over time and differ from those of researchers or other groups of participants [Geoghegan et al., 2016; Hobbs and White, 2012]. Citizen scientists might be more interested in solving issues of daily relevance than learning about scientific problems, methods and research questions — something that professional researchers might assume as the main motivation of participants. According to the different levels of engagement, the aims of communication can be described more systematically: contributory projects with the main aim of data collection and processing follow a "knowledge-first" approach, and co-created projects are more "process-oriented". These orientations will define the aims and means of communication between actors in the projects.

To handle the tasks in CS projects, to address and negotiate main aims of communication, to create and shape the spaces communication actors interact in and discuss their roles in the collaborative process, communication as a tool is an important element. Communication in CS should enable and support both collaboration and the transfer of information and knowledge between actors, and should enhance mutual understanding.

The framework section "Main aims of communication and interaction" can create added value for practical communication in CS. This section helps to identify the specific main aims of communication according to the appropriate type of citizen

and scientist engagement. Thus, it becomes evident that differences are likely to occur in terms of aims of communication — not only depending on the type of engagement, but also depending on the actor.

Meso-level communication and interaction

Interaction space and decision-making

When scientists and members of the public cooperate in the CS research process, they create a common space for understanding and exchange through their interaction and communication. Within this metaphoric space, actors in CS rethink and establish roles and status, responsibilities, values and power relations. The actors' own social reality including social identities and roles are co-constructed. The possibility as well as the need to question and (re-) negotiate assumptions, expectations, and goals by all actors is particularly given in co-created CS projects where partners have an equal say in project decision-making processes. It is therefore necessary to find a common language and to negotiate interests, motivations and interaction. This process of negotiation and decision-making provides opportunities to create sense and meaning between participating actors. Communication therefore is not only the tool for creating reciprocal understanding, but it is also the process. Theoretically, in the most effective CS projects, all people involved are intellectual partners and contributors or collaborators. Thus, CS initiatives challenge the historic divisions between who is part of science and who is not is [Pandya, 2018].

The idea of an interaction space in relation to CS has already been discussed in research. This space is created by the encounter between members of the public and scientists for dialogue and collaboration, knowledge production, and social learning. Wittmayer and Schäpke [2014] use this metaphor to describe participatory approaches in sustainability research, which includes an understanding of activities and roles of actors. Alternative names used in a number of research fields are also given by the authors: transition area and protected space [Loorbach, 2010], arena for dialogue [Greenwood, Whyte and Harkavy, 1993], and communicative or participatory space [Sinwell, 2012; Wicks and Reason, 2009].

One of the most essential parts of the negotiations within the participatory project interaction space, including CS, is related to power relations and ownership within the project. This is an aspect that needs more attention in the scientific discussion of CS [Haklay, 2018; Liboiron, 2019]. Actors need to decide on key points [Bergold and Thomas, 2010] as CS researchers can learn from process-oriented research approaches like participatory research. Here scientists and members of society collaboratively research and influence social realities with the aim of better understanding and changing them [von Unger, 2014]. Stoecker [1999] emphasises who takes control of certain steps of decision-making needs to be defined, for example defining the research question and research process, implementing the design, analysing the data, reporting, and acting on the results. Concerning a more conventionally organised, institutionally managed project, and with respect to the call for more co-created CS projects, collaboration would mean sharing or devolving power and ownership for the scientist and gaining power and ownership for citizens. These questions seem to be highly relevant for CS as they

influence the communication and interaction processes, and subsequent potential roles of actors.

The term 'interaction space' is introduced in the framework (Table 1, column 5) to refer to the interaction capacity, or metaphoric space for actors. Depending on the different types of CS projects and engagement levels of citizens and scientists, operational dimensions can define the interaction space: the frequency and intensity of collaboration, as well as spatial and technical dimensions. The frequency and intensity of collaboration tells us how often citizens and scientists meet during the joint engagement in a project. This meeting frequency can range from a single event to regular meetings over months and even years, for example in long-term monitoring projects or community-science collaborations. The spatial dimension refers to the place where the actors meet. These encounters can happen in an online or virtual space, thus not necessarily implying a synchronous meeting between the actors. At the other end of the spectrum are face-to-face meetings in a physical location, most likely in co-created or community-led projects where communication and interaction are more intense, to discuss e.g. the development of the project, to negotiate interests or for decision-making processes. Communication and interaction thereby can be direct or indirect. For example, scientists could provide instructions or teaching material for participants in an online platform that participants can retrieve whenever they need. Digital technologies are drivers for CS as communication and data collection tools. However, these tools and technology call for their own forms of communication including possibilities and limitations [Newman, Wiggins et al., 2012; Brenton et al., 2018; Mazumdar et al., 2018].

Roles of researcher and citizen

Finally, the framework provides the opportunity to reflect on the role of researcher and citizen both on the micro and meso level (Table 1, column 6).

On the CS project or micro level, the interaction between scientists and citizens might need flexible role making as well as role taking to achieve common goals, especially in projects where tasks differ, as roles might need to be adapted or new ones taken. This flexible role taking and making, according to the interactionist school of thought, means that an individual has to behave in situations and interactions that are uncertain and thus not only need taking the perspective of others to predict actions and expectations and act accordingly, but also make a role. This includes a flexible approach in social interaction. Callero [1994] speaks of using roles as social resources in different ways for different purposes. Adaptable transitions such as this are seen in practice where, for example, a contributory project might develop to include more collaborative activities or educational collaboration, such as the Galaxy Zoo project, where participants were initially asked to analyse data on galaxies, and at a later stage, asked to write a joint scientific paper which is a much more complex task requiring other skills and capacities and lead to a different role [Crowston, Mitchell and Østerlund, 2019].

When taking up new roles, actors require mental flexibility and creativity [Lynch, 2007], which might cause problems at the individual level and in relation to other role actors. Anecdotal evidence has shown that actors in CS do experience role conflicts [e.g. Salmon et al., 2021]. However, scientific literature in the field of

science communication has not yet provided systematic consideration of role conflicts. Role conflicts could be imagined easily: consider a citizen who is also a scientist, though in another field, who is a nature-lover and a family member. If this individual assumes the role of data provider in a CS project, the citizen's other roles can become less salient and less active when performing this new role. Other roles and related skills, values, and expectations will still exist and might in practice still be active, even if less prominent. In addition, problems can arise when the person is unable to fulfil all expectations linked with different roles at the same time; for example, regularly collecting data in nature may clash with family obligations. Those potential conflicts should in the future be considered as cause for participant dropouts or attrition as described by e.g., Eveleigh et al. [2014] or Frensley et al. [2017].

Applying the normative-structural role concept on the meso level allows us to identify the position and status of actors in CS at the social level and possible shifts or transitions, as well as assumptions and expectations towards the groups involved.

The role of the scientist in CS might change from a knowledge producer and provider as in the deficit model [Bauer, 2016; Bucchi, 2008] to a process facilitator in CS [Stoecker, 1999] for example in a co-created CS project (see Table 1, column 6). Roles in the traditional science models are clearly defined and draw a boundary between science and society. According to these models, members of the public are not part of the research project and they are mainly defined by what they are not, that is non-scientists. This line of argument also defines by exclusion who the others are, in this case, the scientists: they are *not* the public. The public are characterised as non-experts with knowledge deficits. Members of the public are in the role of passive information receiver,[1] their status is considered low. The researcher has the role of expert and information provider combined with a high status [Brossard and Lewenstein, 2009; Weingart, 2001; Weingart, 2011].

Role change is linked with altered expectations towards researchers in recent decades. For example, researchers are now expected to engage more with society, to conduct research relevant to it, and sometimes policy [Royal Society of London, 1985; Hecker et al., 2019; Stilgoe, Lock and Wilsdon, 2014]. Fox [1982] for example states that the scientist's role changed from that of a notable admired by citizens to that of a professional whose audience were mainly scholars of the same specialty in the nineteenth century. Weingart [2011] describes a parallel development whereby the specialisation of scientists occurred simultaneously with the popularisation of science. This popularisation was targeted towards an audience characterised by its curiosity on scientific facts and knowledge. In the 20th century, this attribution of the public shifted. Now, the public was characterised by deficits and disinterest for science. As a result, the specialisation of scientists led to the detachment of science from society in so far as the scientist both took the role of knowledge producer and consumer. Science became an exclusive system of knowledge production [Dickel and Franzen, 2016].

Engaging more with society challenges researchers to take on new roles that they might not necessarily be trained in. For example, they might choose the role of

[1] Although it is well acknowledged among communication scholars that reception processes include active elements.

initiator, consultant or collaborator [Stoecker, 1999], change agent, knowledge broker, reflective scientist who reflects processes and interactions, self-reflexive scientist who also reflects on their own role within the collaboration and research process, or process facilitator [Wittmayer and Schäpke, 2014] (see Table 1, column 6). There are high demands for performing these roles that need specific skills and capacities. In research without involving citizens, translating and presenting one's own scientific work and methods to an interdisciplinary or transdisciplinary audience already is demanding [Lüthje and Thiele, 2018; Schuck-Zöller, Brinkmann and Rödder, 2018]. CS demands even more flexibility on the part of the scientist, as dialogue and interaction with different dialogue partners might develop in unforeseen ways and need to be addressed accordingly to ensure the project's further course. Involvement in CS might challenge the researcher's status as an authority, and the status of volunteers might change considerably from that of a member of society defined by deficits to that of an acknowledged expert in a certain field.

Values, power relationships and identity

Both the micro and meso-level of communication and interaction in CS, as categorised in columns 5 and 6 of the proposed framework, allow asking normative questions about values and power relationships. For example: are certain activities such as data collection by citizen scientists less valuable than analysing data or designing the research question? Moreover, are they less appreciated and prestigious? Do scientists in co-created projects lose power, as they may not be in control of all steps of the research cycle? Does collaborative participation go far enough in changing existing knowledge relations? Is changing existing structures even the aim of the process? Does scientific knowledge lose sovereignty over public meanings by including expertise and knowledge of members of society? Are citizens ready to take over power and responsibility for decision-making? Does CS want to change existing knowledge relations or does it work only as long as existing knowledge relations are not questioned? What are policymakers' interests in supporting and enhancing CS? Previous research suggests that policymakers have high expectations of CS and embrace its variety. Yet their conceptualisation of CS does not question existing power relationships [Hecker et al., 2019]. If we detect transitions in social roles in CS, these might be indicators "for transformative change in the social fabric of society" [Wittmayer, Avelino et al., 2017, p. 47].

With a changing understanding of roles, questions arise about how citizens and scientists identify themselves. Who is the scientist in CS? Who is the citizen in CS? How do they define themselves in respect to the roles they play in CS? For example, a person who identifies as an expert for butterfly taxonomy might participate in an insect monitoring CS project on butterflies. Yet, their role might be restricted to data gathering although they might be able to do the analysis as well. Identifying oneself within the social fabric of society and specifically in the context of CS can be important for people. It may be of great importance to individuals whether they self-identify as still belonging to the group of scientists for example, and determine their social identity as such, or whether this self-identity might be challenged with the erosion of boundaries in CS. These questions are grounded in social identity theory. Social identity is defined as a person's sense of who they are based on their group membership(s) [Tajfel and Turner, 2004]. Eitzel et al. [2017]

stress the point that CS participants care about how they are labelled because terminology partly defines who they are and to which group they belong. Other aspects related to identity in CS touch on issues of how participants are attached to the places where they engage and what these places mean to them [Haywood, 2019; Newman, Chandler et al., 2017; Haywood, 2014].

Calling for more co-creation in CS also means reflecting on whether all actors are well prepared and equipped for the process: whether actors are ready to question their roles, status and identity, whether they allow for the sharing of power, and whether they are willing to negotiate and discuss.

Discussion, conclusion and outlook

The proposed framework aims at providing a structured way to capture communication and interaction in and about CS. This structuring is especially important because in reality, CS projects are often far more complex and for example aims of communication or level of involvement can change over time. These changes need flexibility and adaption on the side of project initiators like in the case of a project where citizens were asked to do snow observations across the Pacific Northwest, U.S.A. [Dickerson-Lange et al., 2016]. The project engaged with various volunteers in the beginning of the three snow seasons and gained great outreach but sparse data. In the following years, the scientists shifted the collaboration to an educational activity. They chose to work more closely with an outdoor science school, which led to both better data quality and met the aim of an educational outreach. One key factor was the alignment of the CS activities with the regular activities and interests of science school attendants. However, the scientists had to abandon their aim to gain broad spatial data coverage but get higher quality data on selected sites instead [Dickerson-Lange et al., 2016]. With the change in actors involved and considering their motivation, the aims of communication changed, too.

In simplifying the complexity of communication and interaction in CS, the framework provides the opportunity for researchers, science communicators, and participants to critically reflect on their tasks, aims of communication, their understanding of the interaction space, and their roles as actors in CS. The purpose of the framework is not to suggest linear processes or offer one-size-fits-all guidelines, but rather to offer the opportunity for reflection to both scholars and CS project managers.

To limit the framework to essential variables, we have not further differentiated the actor groups of scientists and members of the public, nor have we included other actors that might be influential in the communication process, such as policymakers or the media. However, the framework does offer the possibility of integrating these actors and defining their involvement.

Future research can use the presented framework as a starting point to further clarify communication and interaction, thus helping to inform explicit instructions so as to enable communication between actor groups who might not share the same knowledge background [Østerlund and Crowston, 2019].

For the further development of CS, Irwin [2015] calls for scientific, institutional and citizenship learning, and puts emphasis on institutional learning. So far, literature on learning in CS has focused mostly on participants' learning. Future research should shed light on the other partner in the research process: the scientist. Scientists need to be aware of their own roles and their own need for learning in and through CS, especially in communication and interaction. Questions should be considered such as: what do scientists learn to engage with citizens to various degrees? What is their self-understanding as scientists? Does the sense of identity change in long-term engagement projects? Research on learning should consider and add to both theoretical frameworks and empirical research, accompanied by an empirical assessment of role understanding.

CS project initiators can use the proposed framework to reflect on aims and roles in their projects. However, it should be made clear what roles they want actors to play, and to design their project as well as their communication accordingly. We also invite researchers to use the framework to structure empirical studies of CS projects and their communication and interactions to develop new research questions. Further research could critically analyse the framework by applying other theories and concepts, such as activity theory, which might provide further insights into communication and interaction in CS.

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