The Many Faces of Participation in Science: Literature Review and Proposal for a Three-Dimensional Framework

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Abstract:

Participatory and dialogic formats are the current trend in scientific communities across all disciplines, with movements such as public participation, citizen science, do-it-yourself-science, public science and many more. While these formats and the names and definitions given to them, are prospering and diversifying, there is no integrative tool to describe and compare different participatory approaches. In particular, several theories and models on participatory science governance and citizen science have been developed, but these theories are poorly linked. A review of existing typologies and frameworks in the field reveals that there is no single descriptive framework that covers the normative, epistemological and structural differences within the field while being open enough to describe the great variety of participatory research. We propose a three-dimensional framework, the participatory science cube, which bridges this gap. We discuss the framework's openness for different forms of participation as well as potential shortcomings and illustrate its application by analysing four case studies.

Keywords: citizen science, public participation, descriptive framework, public engagement with science and technology, participatory research, science governance

Participation in science as an established and currently-expanding field

Looking back at today's leading paradigms in science, future researchers might be tempted to speak of the 'citizen science turn'. Approaches aiming to including the public in scientific endeavours have been prospering across scientific disciplines leading to a multitude of participatory approaches, framed under divergent terms and utilising different structural and organizational methods of collaboration and dialogue: "It is now easier than ever for non-professionally trained people to participate in the governance, regulation, and translation of science, as well as in some of the core activities of science itself." (Prainsack, 2014: 149). Following the 'deliberative turn' in democratic theory and practice (Goodin, 2008), communication and dialogue became increasingly important for science governance and scientific policy advice. This led to the implementation of participatory practices for technology assessment, public dialogues on science and technology issues – especially on environmental aspects of these – and the development of various participatory methods from town-hall meetings to consensus conferences or citizen juries (Joss and Durant, 1995; Durant, 1999; Kasemir et al., 2003; Lengwiler, 2008).

While some disciplines and research fields can look back upon a long history of exchange and cooperation between professional and 'lay' scientists (Silvertown, 2009), the desire to open up science and research has become increasingly important even in fields where society has traditionally been in the role of the *studied object* (as in Political Science, Prainsack, 2014). Increasingly, the public is interested in changing roles and becoming a co-studying subject. Networks and associations in the field of citizen science are emerging and becoming increasingly professionalized, as, for example, the first international conference of the European Citizen Science Association in May 2016 illustrates. At the same time, influential funding institutions such as the German Federal Ministry of Education and Research are launching research grants explicitly for citizen science projects. In part, this paradigm shift towards open science may be the outcome of a bigger social trend. Scientists' unique status as objective keepers of truth and knowledge is being questioned in both public and social-science discourses and citizens are becoming more and more interested in getting a glimpse behind the scenes of academic life. Organizing research and science in a more open, democratic and participatory fashion seems to be an appropriate answer to the phenomena described as "science alienation" (Wilsdon and Willis, 2004; Hagendijk and Irwin, 2006; Stirling, 2008). Apart from citizen science there are various approaches to open science up to the interested public and, in many cases, for collaboration with citizens. Within this movement both the concepts, and the denominations they are given, vary. Participatory science, do-it-yourself-science, participatory health research and public history are just some of the terms used to describe approaches of public inclusion in different scientific fields.

While the plurality of formats, and the names given to them, is stunning, most participatory projects in science and research can be traced back to two main paradigms: the public participates either in a *dialogue* about science (governance) or in *doing science* in its diverse forms. We use the term *dialogic formats* to cover all types of consultations and public discussions, e.g. about nuclear waste management or about potential benefits and risks of genetically modified organisms. The *doing-science-together approaches* invite citizens to take part in the process of generating knowledge. Classic examples of co-research projects are those aimed at monitoring biodiversity (e.g. the Christmas Bird Count, see Silvertown, 2009), but co-researching is also very common outside the environmental and biological sciences.

Although science participation through dialogue and through co-research displays similarities, academic discourses regarding the two approaches have been taken place separately. This holds especially true for typologies and frameworks describing this diverse field. While a focussed framework can better account specific details and enhance distinction within a subset of participatory formats, the lack of a comprehensive basis for comparison and discussion keeps the two discourses in their respective silos and often prevents exchange and mutual learning. In this paper, we aim to bring the two academic discourses together and develop a descriptive framework that covers both dialogic formats and co-research.

The academic discussion both on dialogic as on co-researching projects often takes a normative course, raising questions about the quality of findings or the quality of the process. Many existing frameworks intend to structure and simplify the evaluation of participatory science projects by proposing (assessment) criteria individual projects should meet (Abelson et al., 2003; Lynam et al., 2007; Tippett et al., 2007). However, the implementation of the frequently normative criteria remains unclear: What does 'inclusiveness' in participant selection or 'readability' of the provided information mean? How should these criteria be measured? Unlike many of the normative approaches, we seek to develop a model that describes participatory formats and their similarities and differences.

In developing our model, we first conducted a systematic review of the literature produced in recent years on two aspects of science participation: conceptual frameworks and typologies in science governance and conceptual frameworks in citizen science and other participatory research approaches. We find that there is no genuinely descriptive model that integrates the broad variety of approaches in the field. Therefore, we draw on Archon Fung's (2006) democracy cube, a model for participatory democracy, and adapt it to apply to participatory and dialogic science initiatives of all kinds. In order to illustrate the variety of instruments, projects and mechanisms that the cube helps to describe and frame, we present four examples of participatory science projects and place them in the cube. Finally, we discuss the strengths and limitations of the framework and invite a broader scholarly debate on the cube and other typologies.

Current models and typologies for participation in science

Academic discourse on participation builds on research on participation and deliberation in political science and democratic theory, addressing the roles of the various actors within decision-making processes. When this role-based theory is applied to participation in science governance, scientists are attributed the responsibility to "support (self-)enlightenment of citizens by acting as co-learners" and the role of citizens is to "articulate and develop [their] own interests" and "participate in all stages of political process" (Biegelbauer and Hansen, 2011: 591). The frameworks on dialogue and public participation presented in the following section reflect and build on this aspect. Citizen science goes beyond deliberative participation and considers "citizen knowledge and citizen participation in scientific debate" (Irwin, 1995: 111). Accordingly, the existing frameworks for citizen science reflect this focus on (scientific) knowledge generation and build on the models of research processes. In the following, we will present a review of the essential typologies and frameworks of both fields.

Models for dialogue and public participation in science governance

In the field of dialogic participation, there are numerous typologies and models. Mark S. Reed (2008) gives an exemplary overview of the approaches applicable in environmental management. He includes descriptive, normative, and evaluative typologies without differentiating between them, so that typologies that serve different purposes (describing, assessing and evaluating) are considered as equivalents. In the following, we want to discuss the most important approaches in categorizing public dialogue and participation separately, so that their specific focal points become clear.

The classic: Sherry Arnstein's ladder of participation and similar approaches

Before thinking about participation in science, it appears worthwhile to revisit literature on models for public dialogue and participation. Probably one of the most frequently cited publications in the field is Sherry Arnstein's (1969) ladder of citizen participation, a typology for mechanisms of politically involving citizens. The ladder "which is designed to be provocative" (Arnstein, 1969: 216) is constituted by eight rungs and describes the degree of power control delegated to the citizens involved (see table 1). While all forms of manipulation and therapy count as *nonparticipation*; informing, consulting and placating citizens constitute *different forms of tokenism*. Real *citizen power* is achieved by partnership, even more by delegated power and in its most intense form by citizen control. Even though Arnstein's ladder is, in the strict sense, an instrument for labelling *political* participation processes, we summarize the model here because it has inspired several typologies that follow her normative distinction of good and bad forms of public participation (Chung and Lounsbury, 2006; Wright et al., 2010) – not only in the political sciences but also in the field of participation in *science*.

In a similar vein and as shown in table 1, Rowe and Frewer (2005: 263) differentiate between three different types of public engagement, which differ in the direction the information flows. The first type, *public communication*, incorporates all mechanisms where the initiating agency gives information to the public. The flow of information therefore leads from the sponsors of the mechanism to the public without a formal need for public feedback. In the second type, *public consultation*, the flow of information goes in the other direction and the public provides information to the initiators of the participation process. While the first two types of public engagement do not include a formal dialogue between the conveners of the process and the participants, the third type – *public participation* – implies an exchange of information between both sponsors and public. In order to further describe specific types (and potentially evaluate them scientifically) Rowe and Frewer (2005: 265) broaden the three types of engagement by including six characteristics with binary options. They distinguish participation mechanisms further by (1) whether the selection of participants is controlled, (2) whether they facilitate information, (3) whether participants can contribute information, with or without limits, (4) whether the information provided in the process is set or flexible, (5) whether communication occurs face-to-face or not and (6) whether the aggregation of participant information is facilitated in a structured or in a non-structured way. Based on the first typology of the information flow and the six characteristics of the participation mechanism, the authors identify four communication types, six consultation types and four participation types. Their typology seeks to enable a better description of public engagement within science and technology and beyond.[1]

Instead of closed categories: a descriptive map of science participation

While the two frameworks by Arnstein (1969) and Rowe and Frewer (2005) establish categorical types of dialogue and participation, Bucchi and Neresini (2008) offer a different approach by developing a *descriptive* framework for public participation in science. It takes the form of a two-dimensional coordinate plane where the axes plot continuous variables between two extremes

Table 1: Overview on frameworks for dialogue and public participation.

Author(s)	Categories of typology	Sub-categories
Arnstein (1969): Ladder of Citizen Participation	nonparticipation	manipulation / therapy
	degrees of tokenism	informing / consultation / placation
	degrees of citizen power	partnership
		delegated power
		citizen control
Rowe and Frewer (2005): Typology of public engagement mechanisms	public communication / public consultation / public participation	control of participation selection / facilitation of information / limitation of information contribution by participants / flexibility of the information provided in the process / mode of communication; aggregation of participant information
Bucchi and Neresini (2008): map of public participation in science and technology	intensity of participation in the knowledge construction process	high / low
	degree of spontaneity of public participation	sponsored / spontaneous

instead of concrete values. The first axis captures the intensity of participation in knowledge construction between the two poles of high and low intensity. Similarly, the second axis depicts whether the respective participation mechanism occurs in a sponsored or a spontaneous fashion. The intensity of public participation is ranked in the middle between intensive and basic depths of involvement.

The commonality between the reviewed frameworks for dialogue and public participation is the core issue of inclusion in the normative process of decision-making. The operationalized categories of the frameworks vary from more theoretical considerations of degrees of power-sharing and normative influence on the one side, to more practical aspects for the conduct of participatory processes on the other side.

Models for citizen science

The core issue of citizen science is the participation of non-regular scientists in the process of knowledge generation. The various typologies for citizen science differ in their normative perspectives on the role and function of citizen science and the terminology they use. As summarized by Riesch and Potter (2013: 107-108) citizen science "is a contested term with multiple origins, having been coined independently in the mid-1990s by Rick Bonney in the US (see Bonney et al., 2009) to refer to public-participation engagement and science communication projects, and in the UK by Alan Irwin (1995) to refer to his developing concepts of scientific citizenship which foregrounds the necessity of opening up science and science policy processes to the public." In this paper, we will apply a broad and more descriptive understanding of citizen science as the inclusion of non-traditional, non-institutionalized and non-professional researchers in the process of knowledge generation, including research processes conducted without institutionalized scientists at all (Bonn et al., 2016). The existing models for citizen science can be grouped into three broad categories, described in the following section.

Participation in the different stages of a scientific process

A common approach is to categorize citizen science according to its openness along the prototypical steps of a scientific process from formulating research questions to the actual conduct of research and the subsequent analysis. During the Citizen Science Toolkit Conference, Candie Wilderman (2007) presented three models for what she called community science. The three models are based on the questions "Who is it that is actually defining the problem? That is, who is setting the agenda for the research? Who is it that is actually designing the study? Who is that is collecting the samples? Who is it that is analysing the samples? Who interprets the data?" (Wilderman, 2007; see table 2). These questions represent the steps of a classical scientific process. Depending on the responsibilities for these steps, the models are sorted with an increasing degree of participation by the community in the research process. The 'community consulting model' follows the idea of 'science shops' originating in the Netherlands in the 1970s (Leydesdorff and Ward, 2005). Under this model, the community defines a problem and research task, while the research itself is conducted by professional scientists. The "community workers model" encompasses various collaboratory settings, from public data-collection, through to a collaborative analysis. The 'community-based participatory research model' describes projects where all tasks are conducted by the community, equivalent to participatory-action research approaches (Whyte, 1991).

A similar model describes types of participation in the adaptive management of natural resources informed by (participatory) research (Cooper et al., 2007). The model includes Wilderman's three types with the same specification. Additionally, two more models – 'adaptive citizen science research' and 'adaptive co-management research' – include a feedback loop, in which the results are presented and discussed with the public (either on an individual level or in a broad setting) to adaptively influence data-collection during the process.

In 2009, an expert group prepared a report for the Center for Advancement of Informal Science Education (CAISE) on public participation in scientific research including a typology (Bonney et al., 2009). The typology is also built on the steps of a scientific process, from problem definition to data collection, analysis and interpretation of the results. They define three basic models for public participation in scientific research, with increasing involvement of the public just like a participation ladder: *Contributory* projects (designed by scientists with participation being primarily the collection of data), *collaborative* projects (also designed by scientists, but with more in-depth participation of the public, for example contributions to data analysis or discussions about interpretation) and *co-created* projects (where the public participates in all steps from the beginning to the end; for an overview see Bonney et al., 2009: 17). The authors explicitly state, that they "have deliberately excluded public engagement in science (PES) activities that involve members of the public influencing public policy as opposed to participating directly in research" (Bonney et al., 2009: 19).

In 2012 a group of researchers, many of whom were also authors of the CAISE report, presented an extended version of the typology with five components (Shirk et al., 2012; see table 2). In addition to the three models (contributory, collaborative and co-created projects) they present two more models which fall outside of the hierarchical order of the other three with their increasing inclusion of the lay public. The first, contractual projects, "where communities ask professional researchers to conduct a specific scientific investigation and report on the results" (Shirk et al., 2012) shows similarities to normative policy-influencing participation, but with a concrete project focus. The second, collegial contributions "where non-credentialed individuals conduct research independently with varying degrees of expected recognition by institutionalized science and/or professionals" (Shirk et al., 2012), summarizes projects within the hacker and maker community without the participation of institutionalized scientists.

Observations of participation as it occurs in the wild

A second group of models follows an approach oriented towards the practical implementation of citizen science projects and heuristic observations. Andrea Wiggins and Kevin Crowston (2011) review the earlier typologies based on theoretical research steps and suggest an "empirically-grounded typology of citizen science projects" as an additional approach. They examined a sample of existing citizen science projects and coded them according to 80 criteria which they analysed for common characteristics. As a result they present five different types of projects, differing in project goals and also the role of on-site participation (as opposed to online participation): Action, Conservation, Investigation, Virtual, and Education. This heuristic approach presents a practical perspective on existing citizen science projects from diverse categories. They refined their approach with a cluster analysis based on questionnaire responses from existing citizen science projects. Thus the clusters are built on the empirical data and do not reflect theoretical or systematic considerations. The two main categories considered for the definition of the clusters were participants' tasks within citizen science projects as well as the stated goals of the project (Wiggins and Crowston, 2012).

Focussing on participation in environmental science, Janis L. Dickinson and Rick Bonney (2012) present a framework for citizen science projects with four major axes, which is also based on a heuristic approach looking at practical aspects of project implementation. They describe the axes as follows, "(1) initiator of the project, professional scientists or the public; (2) scale and duration of the project, whether local or global and short term or long term; (3) types of questions being asked, ranging from pattern detection to experimental hypothesis testing; and (4) goals, which include research, education, and behavioural change (e.g. towards environmental stewardship)" (Dickinson and Bonney, 2012: 6).

Barbara Prainsack (2014) proposes a typology for citizen science based on six main characteristics that address different structural aspects of the respective project, namely its (1) coordination (agenda setting; decisions about results, intellectual property etc.), (2) participation forms and processes (profile of participants, resources required to participate etc.), (3) relationships toward communities (relation to existing communities, facilitation of building new communities etc.), (4) evaluation (definition of 'success', handling of the results), (5) openness (access to data and findings; acknowledgment of participants' contribution etc.) and (6) entrepreneurship (funding, economic use of the results, roles in the project). To illustrate the meaning of each feature she proposes related questions, for example, who decides on the evaluation criteria? Do participants take part in establishing the core datasets? What are the prerequisites for joining the project?

Chiara Franzoni and Henry Sauermann (2013) present a framework for what they refer to as crowd science, which differs in approach and focus from the other frameworks discussed here. It distinguishes on one axis the openness of project participation and on the other axis the disclosure of intermediate inputs such as data or algorithms. The two axes come together to form a four-quadrant diagram. The framework is limited in its scope and does not include further-reaching forms of participation and empowerment. Also, the tailoring of the framework and the chosen examples show a clear emphasis on online-collaborations.

Participation within a normative hierarchy

The third group of models focuses on the normative dimension of openness and participation. Muki Haklay (2013) describes a framework similar to the various frameworks presented earlier which consider participation in the different steps of the scientific process. He proposes four levels of participation: level 1: crowdsourcing, level 2: distributed Intelligence, level 3: participatory science, level 4: extreme citizen science. With this categorization under explicit hierarchical labels, he draws on the concept of the participation ladder, with a normative reasoning, "the participation hierarchy can be seen to be moving from a 'business as usual' scientific epistemology at the bottom to a more egalitarian approach to scientific knowledge production at the top" (Haklay, 2013: 118).

This ranking of participation is reduced to a normative-laden binary framework presented by Finke and Laszlo (2014) with the two main categories "citizen science light" for activities, where citizens only contribute by collecting data or assisting in simpler tasks, and "citizen science proper" where citizens are equal partners with professional scientists in a joint project.

Our review of models of citizen science shows that the common issue of including non-professional participants in the process of knowledge generation is the defining element of distinction in some typologies, while others consider more practical aspects for differentiation. The focus of the citizen science frameworks varies between theoretical and normative considerations, ranging from the degree of influence on the epistemic process, to the more practical aspects of the implementation of citizen science projects.

Table 2: Overview of frameworks for citizen science projects.

Author(s)	Categories of typology
Wilderman (2007) * Cooper et al. (2007) †	community consulting model †* / community workers model †* / community-based participatory research model †* / adaptive citizen science research † / adaptive co-management research †
Bonney et al. (2009) * Shirk et al. (2012) †	contributory projects †* / collaborative projects †* / co-created projects †* / contractual projects † / collegial contributions †
Wiggins and Crowston (2011)	action / conservation / investigation / virtual / education
Dickinson and Bonney (2012)	initiator of the project / scale and duration of the project / types of questions being asked / goals
Prainsack (2014)	coordination / participation / community / evaluation / openness / entrepreneurship
Franzoni and Sauermann (2013)	project participation / disclosure of intermediate inputs
Haklay (2013)	crowdsourcing / distributed intelligence / participatory science / extreme citizen science
Finke and Laszlo (2014)	citizen science light / citizen science proper

Bringing the two worlds together?

The academic discourses on frameworks for participatory science governance and citizen science with its different connotations, including fields like participatory action research, have so far been mostly divided into the siloes of their respective academic tradition. Furthermore, a joint discussion is hindered by delimiting terms and definitions and normative-laden models which disregard a wider perspective.

There are some analyses of participatory science which include aspects of discursive participation and contribution to the research process. One example is the case of "contractual projects" included in the framework (Shirk et al., 2012), with communities requesting specific research projects, often focussed on a local issue affecting the community and relevant for decision-making. Another is the Green Paper "Citizen Science Strategy 2020 for Germany", discussing "Incorporating Citizen Science Results into Decision-Making Processes" (Bonn et al., 2016: 10) or the report from a workshop focussing on participation and citizen science from the process leading to the strategy (Pettibone et al., 2016). Wehling (2012) distinguishes "invited" participation (e.g. stakeholder dialogues) and "uninvited" participation (e.g. community activism) from a technology assessment perspective. Haklay (2013) cites Arnsteins (1969) participation ladder when developing their citizen science model, but only briefly discusses the structural connections and differences between citizen science typologies. Sabine Maasen and Sascha Dickel (2016: 236) refer to both aspects in the "Handbuch Wissenschaftspolitik" with a consideration of "normative questions – empirical answers".

Jason Corburn (2005) refers to the collaboration between local and academic knowledge for problem-solving as 'street science'. His concept includes participatory knowledge-generation as well as decision-making and builds on the understanding of participatory action research and the co-production model of expertise, where not only the methods of research but also the definitions and framing of the problem are decided on via a participatory approach (Corburn, 2015: 19).

A publication exploring the 'public engagement rhetoric' in the field of biomedical research defines three modes of public participation in science: participation, engagement and involvement (Woolley et al., 2016). In their model, *participation* "suggests an active, intentional role, but can also describe quite passive forms of inclusion", *engagement* means that "members of the public can be more or less engaged in scientific studies, depending on the extent to which scientists seek to communicate their plans and solicit the public's cooperation in collecting data" and *involvement* implies that "members of the public have an active role in in the planning and conduct of the research itself, even to the level of choosing the scientific questions to be addressed" (Woolley et al., 2016: 2). The authors combine the three terms into an overlapping Venn-diagram, where e.g. pure participation means crowdsourcing or the overlap of participation and engagement "classical citizen science" (Woolley et al., 2016: 3). However, the definition of the framework, along with the chosen terminology, seems to be ad-hoc and does not reflect the existing academic discussions of the terms and their meanings. Also, the framework seems to be inconsistent, for example 'public deliberation' is not seen as being part of 'involvement' although it would fulfil the definition of "having an active role in in the planning (...) of the research" (Woolley et al., 2016: 3).

Drawing a broader and more conclusive picture building on the existing frameworks, Dick Kasperowski has described the field of citizen science as consisting of three forms, including governance discourse and research contribution: "Citizen science describes at least three things: 1) citizen science as [a] mere research method, which aims at producing scientific results. 2) citizen science as public participation, with the aim of creating legitimation for science and science policy within society 3) citizen science as citizen mobilization, with the aim of exercising legal or political influence on certain issues" (translated from Herb, 2016; see also Kasperowski and Brounéus, 2016).

While these approaches have started a push towards a common framework for participation in science and presented some components of it, they have not yet presented a comprehensive and systematic typology of the field.

Proposal for a three-dimensional framework: the participatory science cube

The various models and frameworks for participation in science presented above have in each case been developed from the perspective, and within the tradition and context of, a *specific academic discipline*. While some models span across more than one field and consider multi-disciplinary aspects, most focus on specific aspects

Despite their differences, all the described models are built around a one-dimensional scale and a linear hierarchy of categories. While this does allow for a detailed analysis, albeit from a rather narrow angle of view, it hinders a holistic consideration of all forms of dialogue and participation as different manifestations of participation in science. To overcome this hurdle and consider the many established forms of participation and the diversity of approaches, a framework has to be built with more than just one dimension.

In this vein, Susan Stocklmayer (2013) developed a three-dimensional model for science communication that she named the "science communication field". It differentiates between the sender of the communicative message (axis 1), the receiver of the message (axis 2) and the intended outcome of the respective communicative act (axis 3 with three categories: one-way information transfer, knowledge sharing or knowledge building). The *science communication field* demonstrates the usefulness of three-dimensional models; but while its focus on communication and the involved entities (sender/receiver) is useful within science communication, it is too specific for the diverse forms of science participation. Stocklmayer's (2013) model shows that the connection of three dimensions into the analysis of a complex communicative process is helpful in modelling and developing methods to analyse a rapidly developing sphere at the interface between science and society. Nonetheless, her communicative approach meets a demand that is not ours, as we focus on *participation in* science rather than *communication about* it. Also, the very granular design of this model makes it poorly suited as a broad unifying model of participation in science.

The idea of a multi-dimensional framework with a specific focus on *participation* was proposed by Archon Fung in 2006. His 'democracy cube' describes deliberative participation in governance, but with a generalization and re-focussing on participation in science. The framework can be expanded to develop a three-dimensional 'participatory science cube', which is able to locate the broad variety of participatory formats – from science policy dialogues to citizen science projects – in a joint space. The established categories conceived in Fung's model serve as basis for the axes of the participatory science cube.

The idea of bringing together concepts of political participation and participation in science is not new and has been taken up by concepts such as scientific citizenship (Irwin, 2001): "[scientific citizenship] implies not only that scientific knowledge is important for citizenship in contemporary society but also that citizens can lay a legitimate claim to accountability in scientific research. As such, the notion can be perceived as a normative ideal concerning the appropriate form of democratic governance in a society that has become increasingly dependent on scientific knowledge" (Horst, 2007: 151). Participatory governance and participatory science follow similar goals: opening up systems to new groups with previously rather closed mechanisms (decision-making on the one hand and scientific knowledge production on the other hand). With this paper, we want to bring these two discourses on participation together: we have started with a review of both aspects in the previous sections, we discuss the democracy cube in the next section and, finally, propose a new framework for science participation based on Fung's democracy cube.

Origin: the "democracy cube" by Archon Fung

Archon Fung's framework for describing the variety of possibilities for political top-down participation comprises three dimensions that frame (1) who participates, (2) in which ways the participants communicate and decide and (3) how these discourses and decisions are integrated in the political context.

Fung describes three main factors that make a description of participatory instruments necessary. Firstly, different forms and instruments of political participation exist in modern societies. They offer different modes and depths of involvement and address different institutions. However, it remains unclear how to compare them, as "there is no canonical form" of direct political participation. While normative categories have been proposed, there is a lack of descriptive tools, which the democracy cube intends to remedy. Secondly, political values, such as equality of participants or a respectful dialogue process, are hard to quantify and even harder to compare on a large scale. Therefore, it is more useful to describe the mechanisms of participation rather than attempting a normative approach based on abstract values. Thirdly, participatory instruments are very often tightly intertwined with other forms of political decision-making in representative structures and bodies. Analytically, it is difficult to draw the line between public participation, representation and administration. The democracy cube is an inclusive model that can describe mixed forms of political participation and even political decision-making without citizen participation at all.

In short, the democracy cube integrates three dimensions and creates a space where the different kinds of participatory mechanisms in politics can be placed. It defines democratic participation based on its method of participant selection, its modes of communication and design, and the authority and power delegated to the participants. In the following, we briefly summarize the three axes and their main categories.

Fung's three dimensions: who participates? How? Who decides?

The first dimension – Participation Selection Methods (axis #1) – asks who is eligible to participate and differentiates between five common participant selection mechanisms. The most open approach consists of *inviting all those who*

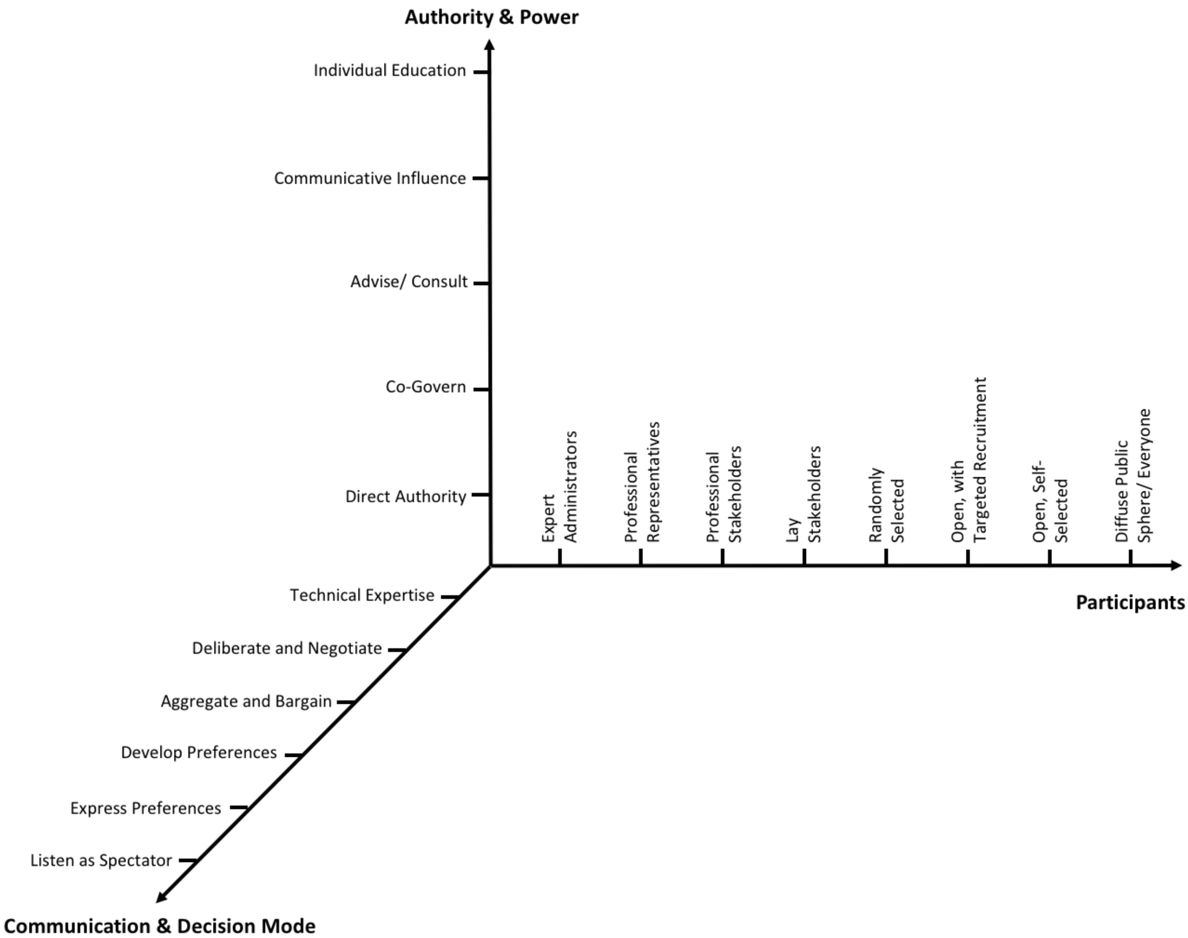

Figure 1: The democracy cube as introduced by Archon Fung (2006).

wish to participate so that the participants are a self-selected sample of the general population. Altogether, eight methods of addressing participants are located along the axis according to their degree of inclusiveness.

The second dimension – Communication and Decision (axis #2) – examines the question of how the public participates and presents three ways of communicating (listening as spectator, expressing preferences, developing preferences) and three forms of decision-making (aggregating and bargaining, deliberating and negotiating, deploying technical expertise).

The third dimension – Authority and Power (axis #3) – frames the question: how much power does the specific mechanism of participation delegate to the participants? Do the citizens have a say in the process and decision-taking or is their primary benefit personal (through learning, social ties etc.) The power and authority dimension of Fung's democracy cube covers five types of political influence, from processes where participants benefit mostly personally to mechanisms where they exert direct authority.

Participation in three dimensions

The three dimensions combined constitute a descriptive three-dimensional space – the democracy cube (see figure 1) – that facilitates describing and comparing different participatory mechanisms according to who participates, how decisions are taken and by whom.

Adapted model: the 'Participatory Science Cube'

The axes of Archon Fung's (2006) democracy cube represent the central dimensions of participatory governance. In order to build a joint framework for deliberation and dialogue on science and science policy together with participation in the scientific process of knowledge generation, it is necessary to consider the underlying issues which impact on the actors.

By including all kinds of participation in science we follow the interpretation of Trench (2006, 2008) and Stocklmayer (2013), that participation in science is a *continuum* that moves between the two poles of (1) one way communication (including all forms of promotion of science) and of (2) two-way communication (including all scientific activities of building knowledge together, e.g. citizen science). In addition, a broad notion of participatory science might inspire science communicators (who focus on one-way communication) to become more open to dialogic or even collaborative formats.

Dialogues are carried out to address the question of *what ought to be done* (and may result in a policy, decision, recommendation, etc.). Therefore, dialogues and deliberative participation approaches open up the *normative dimension* of science. Rather than scientists[2] alone deciding on the course and conditions for their research, the public or its representatives are included in the decision-making process. The degree of participation varies, as described in the various models for dialogue processes, summarized above. Meanwhile, the conduct of the research within the agreed rules and guidelines remains in the hand of the scientists.

In contrast to dialogues, citizen science projects address questions of *what and how we know*: the process of knowledge generation and validation is opened up towards 'lay' people. Depending on the project, scientists may seek citizens' support for research tasks, their specialized (e.g. local or practically informed) knowledge or their collaboration on data analysis and interpretation. Therefore, the core issue for participation in citizen science is the *epistemic contribution*. The range of participatory possibilities is described in the various frameworks for citizen science.

Looking at Archon Fung's (2006) 'democracy cube' which is designed to describe governance in general, it becomes clear that the third dimension for a participatory science framework should also be led by the question of who participates. The participants may range from stakeholders with specialized knowledge and/or legitimacy from societal sub-groups like non-governmental organizations to the general public.

Putting these aspects together, Archon Fung's 'democracy' cube can be transformed into a 'participatory science cube', incorporating dimensions derived from the previously discussed models and describing the various modes of participation in science using a single three-dimensional framework: the first axis of the cube is the normative focus (close to Fung's dimension of "Authority & Power" which is also a normative component), the second axis is the epistemic focus (showing which aspects the knowledge process citizens contribute to) and the third axis is the public (out-)reach (which is, in principle, equivalent to Fung's "participants" axis). This proposed structure is also partly reflected in Jason Corburn's (2005) considerations, when he discusses the benefits of local knowledge for research as well as policy-making. He proposes four categories for participatory benefits for decision-making, one being epistemology as also proposed here. The other three categories (procedural democracy, effectiveness, distributive justice) represent a more fine-grained view of normative aspects, including the reach of participatory processes encompassed in the aspect of procedural democracy (Corburn, 2005: 71).

All three axes describe a continuum between primary actors being scientists at one end and the public at the other end. The positioning of a participatory science project along these axes describes the relative balance and focus of the components between a traditional institutional science project and an open public project. The further out a project is located, the more responsibility and empowerment lies with citizens for that dimension. The subdivision of the axes into distinct categories primarily serves as point of orientation, as the boundaries between the various steps can be blurry and categories may partially overlap for certain projects.

Dimension 1: Normative Focus

The axis describes the degree to which the public is included in decision-making on science and technology governance, for example in priority

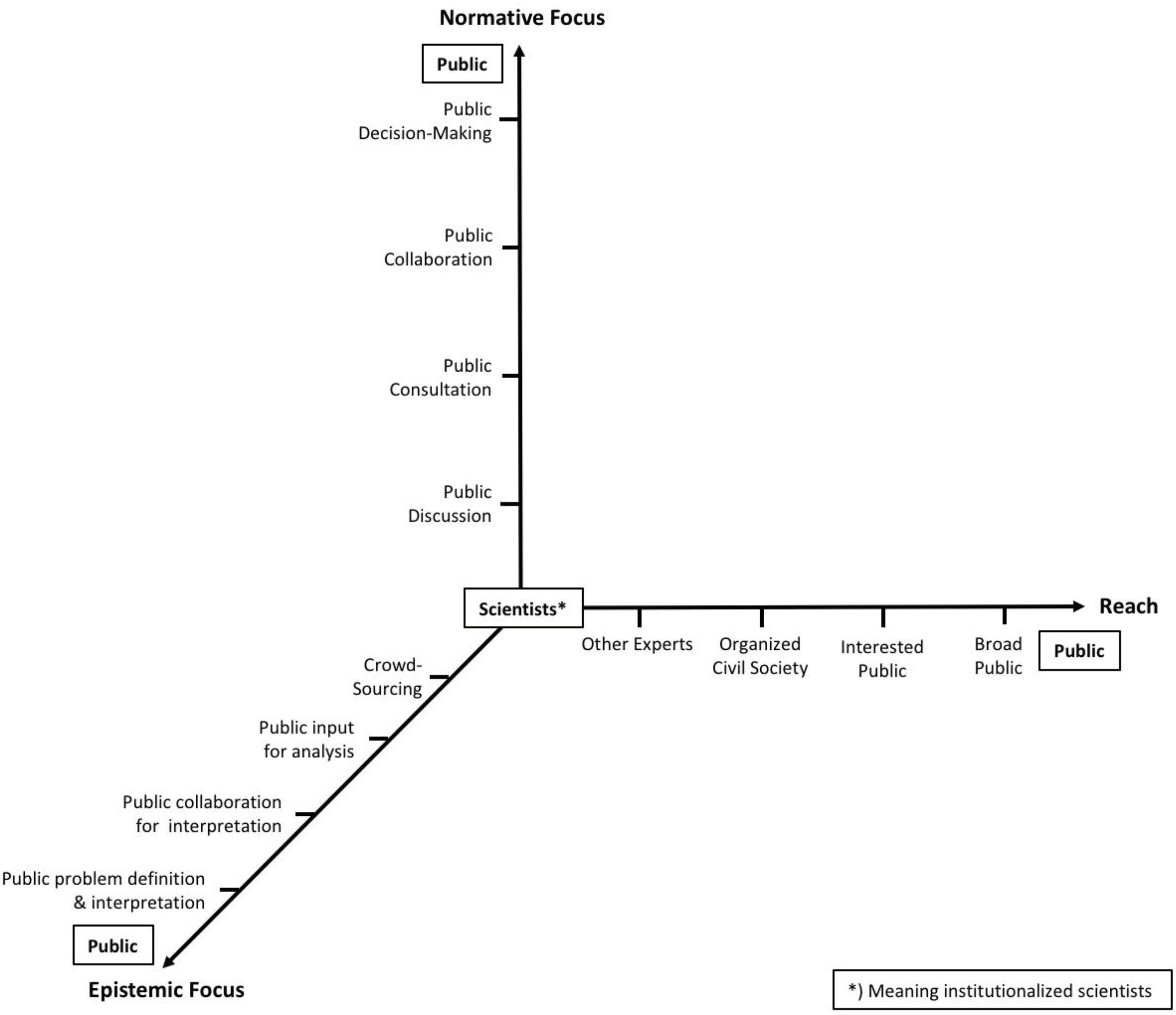

Figure 2: The participatory science cube.

setting, funding allocations, legal restrictions on, or support for, science and technology; or assessment of scientific policy advice. This category considers questions of values and norms as well as questions of preferences and interests. The proposed subdivisions for the axis are derived from the common elements of deliberative participation frameworks described in section "Models for dialogue and public participation in science governance" – from public discussion, to consultation and collaboration, up to public decision-making.

Dimension 2: Epistemic Focus

The axis depicts the degree to which actors other than institutionalized scientists are included into the epistemic process of knowledge generation. The more the public is involved, the more epistemic weight is attributed to them in the research endeavour. In contrast to the normative axis, the epistemic focus considers a specific issue at stake. Therefore, an increasing public contribution, up to the stage of problem definition by the public, means an increased normative say within the project and the limited set of project participants. The overall normative focus on research in general, or even the field of science the project originates from, is not affected. The suggested elements dividing this axis are derived from the common elements of frameworks for citizen science in section "Models for Citizen Science", which are built around the scientific process, from taking over simple tasks in the form of crowdsourcing, to a more in-depth public input, to public collaboration on the interpretation of data, to involving the public in problem definition or the public interpreting data independently.

Dimension 3: Reach

This axis represents the reach of a project beyond institutionalized scientists. The proposed divisions of the axis are modelled on a simplified version of Archon Fung's "participants" axis. They range from experts from other fields (e.g. relevant experts from industry, civil society organizations, administration or politics as well as scientific experts from other disciplines from the original project), to organized civil society associations, the interested public and the general public. The categories are meant to cover the field as broadly and inclusively as possible. The definition of the total public that could be reached by a given project is debateable. It could be a regional community for regional issues through to national populations or even the whole world population. This aspect needs to be addressed when the participatory science cube framework is applied. Furthermore, one needs to take into consideration the design and intended reach of the project versus the reach actually achieved. In the discussion of a case study, it should be clarified whether a low turnout is an inherent issue in the design and implementation of a project (and thus should affect the classification of the project) or based on individual circumstances or the implementation of a certain instance of the project.

Discussion

The participatory science cube provides a common space to visualize and discuss various participatory approaches. The cube constitutes a descriptive framework on a macro level and is intended to provide a basic typology. The participatory science cube aims at reflecting the heterogeneity in the field of science participation while at the same time offering categories to structure the diversity. It allows users to compare and distinguish participatory approaches across the wide spectrum of epistemic and normative influence on the conduct of scientific research. The participatory science cube makes it possible to draw a broad and comprehensive picture of the opening up of science and the development of new forms of collaboration and exchange. Moreover, it can be used to consider questions comparing different situations, e.g. do the natural sciences interpret and exercise science participation in a different way from the social sciences? Does science participation in the Anglophonic world look different from the Spanish-speaking world, as Greco (2004) suggests? The cube is a practical analysis tool to test hypotheses and to comprehend different practices.

The goal of the participatory science cube is not to represent projects in detail and reflect on the often nuanced and important differences between them, for example with respect to project goals, decision-making and power distribution within the project, or social context and understanding among the participants. For this, the tailored frameworks for description and analysis remain the method of choice. In addition to these frameworks we find it important to debate and analyse aspects besides the established categories (e.g. influence and empowerment), for example pleasure and delight experienced by participants, as Sarah Davies (2014) has proposed.

While the three axes span a full space for possible project locations, not all areas are equally likely. First, we expect some correlation between a strong epistemic focus and a strong normative focus, since when citizens have a strong say about the direction of research, this usually implies a strong normative component. As described above, the framework distinguishes between the normative influence limited to the project boundaries (which is considered for the categorization of the epistemic focus) and the normative openness beyond the immediate participants. However, drawing this line can be difficult and remains subject to individual judgement. Second, the reach correlates with the degree of publicness regarding the normative and epistemic focus: a participatory project with public influence has to have a reach beyond scientists and policymakers. Nevertheless, the usefulness of the framework to describe and distinguish participatory projects is not impacted by these predicted correlations.

When applying the cube to analyse existing citizen science and participatory approaches, the cube shares a limitation with the existing frameworks: the projects can rarely be categorized and located exactly, because their openness (on any of the three axes) varies between project components and also over time. Different actors may also

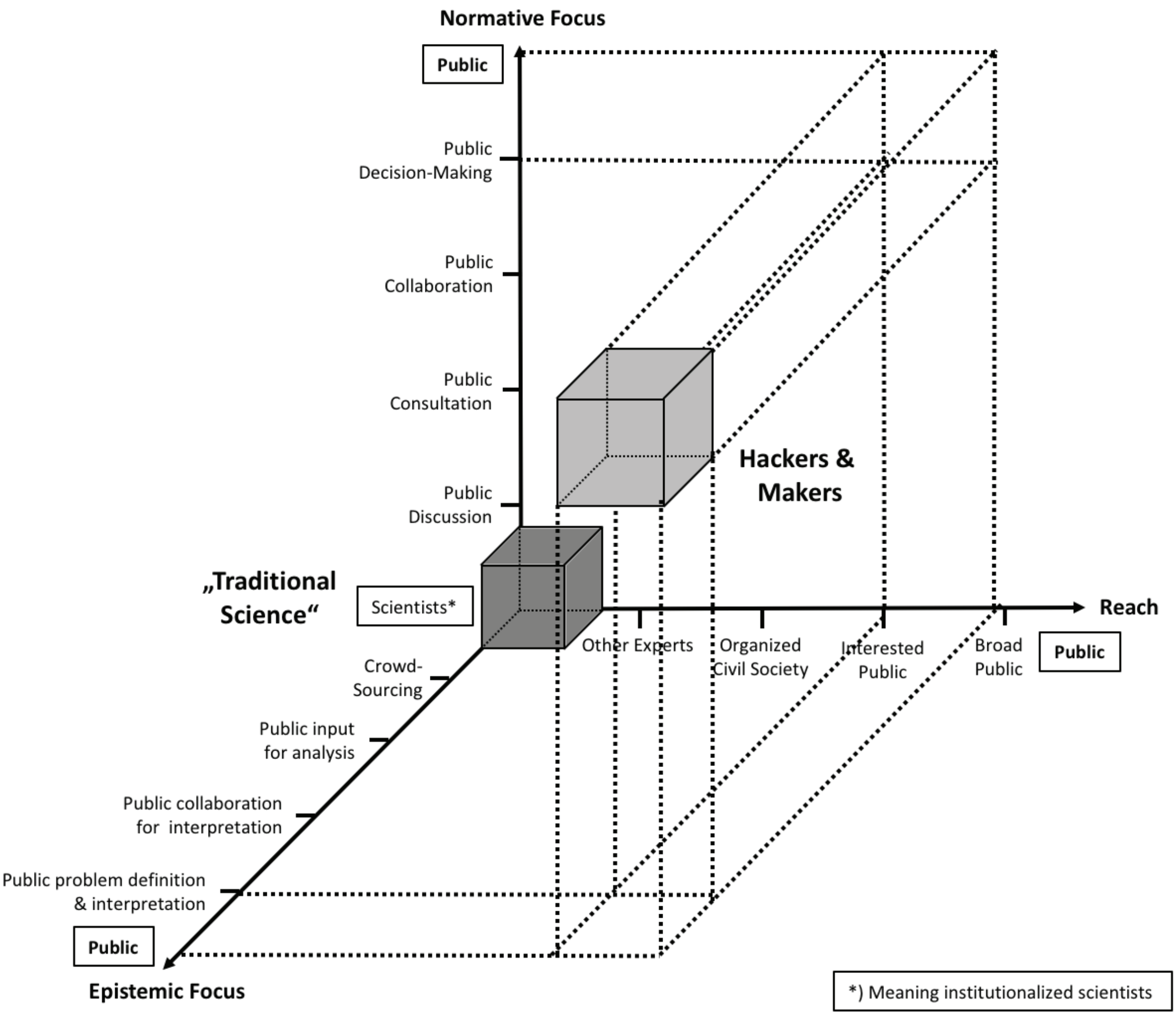

Figure 3: The participatory science cube with two prototypical manifestations of scientific projects on the opposite edges of the cube: traditional, closed, institutionalized science and open hacker or maker projects.

have different positions on the direction of the project. To address this, the projects within the cube are not represented as spots, but rather as areas. We chose cubes to illustrate our example, but stretched clouds and blurry boundaries are also possible.

To illustrate the rationale of the participatory science cube, we have inserted two prototypical manifestations of scientific projects, located in opposite corners of the cube (see figure 3). These manifestations are: 1) traditional, institutionalized science and 2) open hacker or maker projects. Traditional science means a project solely conducted by researchers from traditional scientific institutions without any public input and participation. This type of project is positioned in the back corner of the participatory science cube and reaches no degree of openness on any of the three axes. At the opposite corner of the cube are projects from the hacker/maker/fablab/DIY-science community (Wohlsen, 2011; Hatch, 2013; Walter-Herrmann and Büching, 2014). The DIY-science community promotes the conduct of scientific experiments outside established institutions with the purpose of democratizing science and also achieving educational outreach. Although the maker and fablab movements have a stronger focus on invention, innovation and technological developments, there is a large overlap with scientific research, especially since technology and new measurement approaches play an ever increasing role in today's research. Furthermore, specific projects like "science hack days" (Ornes, 2016) deepen the interaction between technologically motivated communities and scientific endeavours. These projects are placed at the maxima (most public classification) on the axes for the normative and epistemic focus within the participatory science cube. This position is justified by decisions being made solely by community members and the research activities being coupled with a strong set of normative beliefs in empowerment through science and technology and the concept of open science (Bartling and Friesike, 2014) similar to the ideas of participatory action research (von Unger, 2014). Scientific institutions are only included when they act as partners, for example when they provide access to laboratory equipment or machinery. Regarding their reach, these projects do not generally reach a broad public, as only the interested (and often also to some degree previously trained) participate intensively.

Populating the cube with case studies

We have stated that the participatory science cube bridges a gap in existing research regarding public inclusion in science. To illustrate that the cube makes it possible to map very different participatory science initiatives, we briefly present four different approaches to 'public science' and depict them on the cube. The selected projects represent quite different cases and have been selected in order to present the usefulness of the cube as an analytical and descriptive tool. The chosen examples are not intended to be exhaustive, but intend to inspire further applications of the cube. To cover a broad range of case studies, we followed a "most different systems design" approach (see Seawright and Gerring, 2008).

Crowdsourcing to identify African animals: Chimp&See

The first project, "Chimp&See", is a typical citizen science project that invites the general public to assist researchers in identifying species and describing their behaviour and general appearance. On a web-based platform, videos from camera-traps can be analysed and annotated by volunteers. The more 'lay researchers' take part, the more data are gathered and verified through multiple encoding. Participants do not need detailed biological knowledge: they receive a short introduction to their task, view images of wild animals online, identify the depicted species (supported by an identification key), as well as individual animals if possible, and annotate the animals' behaviour (Arandjelovic et al., 2016).

- **Normative Focus:** While participants may benefit personally by acquiring deeper knowledge of wild species and their behaviour and by taking part in a collaborative generation of knowledge, the normative dimension plays a minor role, only marginally contributing to a general discussion of species conservation and diversity beyond the immediate participants. The project is therefore located at the least public end of the axis, only reaching 'public discussion' at maximum.

- **Epistemic Focus:** The performance of repetitive tasks with a focus on pattern recognition is typical of a crowdsourcing project. Besides the encoding of the images, community-engagement activities and user support/motivation via social-media activities, public participants are not included further into the research process. The discussion between participants in the online forums, however, is sometimes taken up by the initiators of the project and may, in some cases lead to modification of the coding schemes. As this happens only occasionally, the epistemic focus for most participants is crowdsourcing (see also Data Shift, 2016), leading to the overall placement along the axis.
- **Reach:** The platform is open to anybody and therefore potentially addresses the general public. However, the voluntary work on animal identification and even the discovery of the platform requires prior interest in the topic. Typical participants are therefore characterized as belonging to the interested public.

Discussing emerging issues in science and technology: Citizen Dialogue on Future Technologies

The second example project is a dialogic format initiated by a government entity. The "Citizen Dialogue on Future Technologies/Topics", initiated by the German Federal Ministry of Education and Research (BMBF), was a national consultation process between 2011 and 2013.[3] The consultation covered one topic each year, with a total of three topics: energy technologies, high-tech medicine and demographic change. The consultation consisted of several aspects: for each topic six to eight citizen conferences with around 100 randomly-selected participants in cities across Germany, accompanying smaller citizen workshops, an open online-platform for comments and discussion, and a final citizen summit for each topic with participants from the earlier events. A roundtable with representatives from science, civil society and industry accompanied each process (Decker and Fleischer, 2012).

- **Normative Focus:** The aim of the consultation was to incorporate the perspectives of citizens regarding future technologies into advice for policy-makers. The policy advice was addressed through a final 'citizen report' developed by the participants of the citizen summit, based on the input from the whole dialogue process. This report had no binding implications for policy makers, but was distributed to politicians, administrators, and science, industry and civil society organisations involved in the process. The overall classification therefore places the project between 'public discussion' and 'public consultation'.
- **Epistemic Focus:** The citizen dialogue focused on governance issues ranging from research priority setting to potential limits on research. The participants had no systematic involvement in research processes (aside from a potential influence on individual participating researchers). Thus this project has no epistemic contribution in the framework and is located at the inward end of the axis.
- **Reach:** Although the number of participants in the discussion events was limited, the random polling (achieved through random phone calls with invitations to the events) and the geographically distributed events across the country ensured that not only the interested (typically highly-educated, older, male participants) contributed to the debate. To account for the response bias during the random selection, underrepresented groups were given priority for registration. Additionally, the online platform was open for anybody to participate. Therefore, a very broad public was reached with the project.

Scientific societies with profound 'lay' knowledge: the ORION entomologists

The third example is a scientific participatory format that has existed even longer than the term 'citizen science'. This long-established form of lay science takes place in scientific societies whose members share a common passion for a specific branch of science and work on it for years, acquiring skills and knowledge often superior to professional scientists. The entomological society "Orion", situated in Berlin, was established more than a hundred years ago. It is an example of 'lay experts' who intensively cultivate a special interest (e.g. for beetles), so that they gain a profound expert knowledge and publish their results in entomological publications, for example in the national inventory of beetles (Stiesy, 1990).

- **Normative Focus:** While the society also holds public presentations and the members are engaged in environmental conservation, the overall activities, beyond the members themselves, have no normative component with respect to science policy. In contrast to the hacker and maker community, traditional scientific civil society organisations like ORION mostly work within the established fields and procedures of institutionalized science. Therefore, they are not considered as a normative opening within the framework.
- **Epistemic Focus:** The members of the society define their own epistemic focus, conduct long-term research projects on certain species or go on excursions to collect data in specific areas. They also perform the analysis independently (and have, for example, negotiated permission to use the collections and part of the technical infrastructure of the Museum of Natural History in Berlin for reference) and publish their own results. The project therefore reaches the most outward public epistemic focus in the participative science cube framework.
- **Reach:** The activities of ORION are primarily limited to the members of the society. Even though presentations and excursions are open to the public, the reach beyond the members is limited. The society's reach is therefore categorized as organized civil society within the framework.

Scientific activism in air pollution monitoring: the Diamond bucket monitoring

The fourth and final example illustrates the importance of scientific data and evidence for lay citizens who wish to immediately influence political decisions. The inhabitants of the Diamond subdivision in Norco, Louisiana decided in the late 1990s to take scientifically-based actions on the air pollution they experienced living close to a Shell chemical plant. Fearing for their physical health, they started monitoring air pollution using simple sampling devices they referred to as "buckets". While the sample-taking was performed by the citizens, the actual analysis was performed with professional laboratories. The main issue of the conflict was not the measured values themselves, but the question of the definition of environmental standards (mean long-time exposure vs. local short-term exposure) and the official measurement frequency and distribution of measurement points (Macey, 2003; Ottinger, 2010).

- **Normative Focus:** While the overall goal of changing environmental standards and methods for monitoring was not achieved, the activists created public awareness and forced the Shell Company to initiate a multi-year supervised study of the local air quality and "may have contributed to regulators' decision to take enforcement [action] against Shell Chemical" (Ottinger, 2010: 246). Therefore, a true public decision-making was not achieved, but a public collaboration on the evidence-based enforcement of environmental standards was achieved.
- **Epistemic Focus:** Driven by a practical problem and serious health concerns, the inhabitants of communities neighbouring the chemical plant decided to start self-organized air monitoring. The community themselves addressed the problem definition, measurement strategies, sample taking and interpretation of the results (including the discussion of official standard definitions). The chemical analysis of the sample was performed by professional laboratories, but this would also have been the case had official experts measured the air quality. Therefore, the most participatory categorization with regard to the epistemic focus is still justified.
- **Reach:** The activities of the Diamond inhabitants were in principle open to the general public. However, only the community immediately affected by the problems constituted the core group of participants. Therefore, and because of the limited geographic reach, the project has not been placed in the most open category with regard to its reach.

The example projects within the participatory science cube

When the four example projects described above are visualized in the participatory science cube (see figure 4), the strengths and limitations of the descriptive framework become obvious.

On the one hand, the cube proves its value in categorizing and visualizing deliberative participatory approaches together with epistemic participation. It provides a good and easily accessible overview of different varieties of participation and can serve to inform further debates and developments. Also, when multiple projects are visualized in one framework, it is possible to identify participatory blind spots, where no projects exist so far. Also it may serve as a descriptive tool to grasp the evolving and popular field as citizen science. On the other hand, the examples show the limitations of the model: for the exact positioning of the projects within the cube, reasonable judgment is necessary. This may lead to different categorizations by different observers. Therefore, the visualization alone does not present a complete characterisation of the projects, since additional information and justification for the categorization is always necessary.

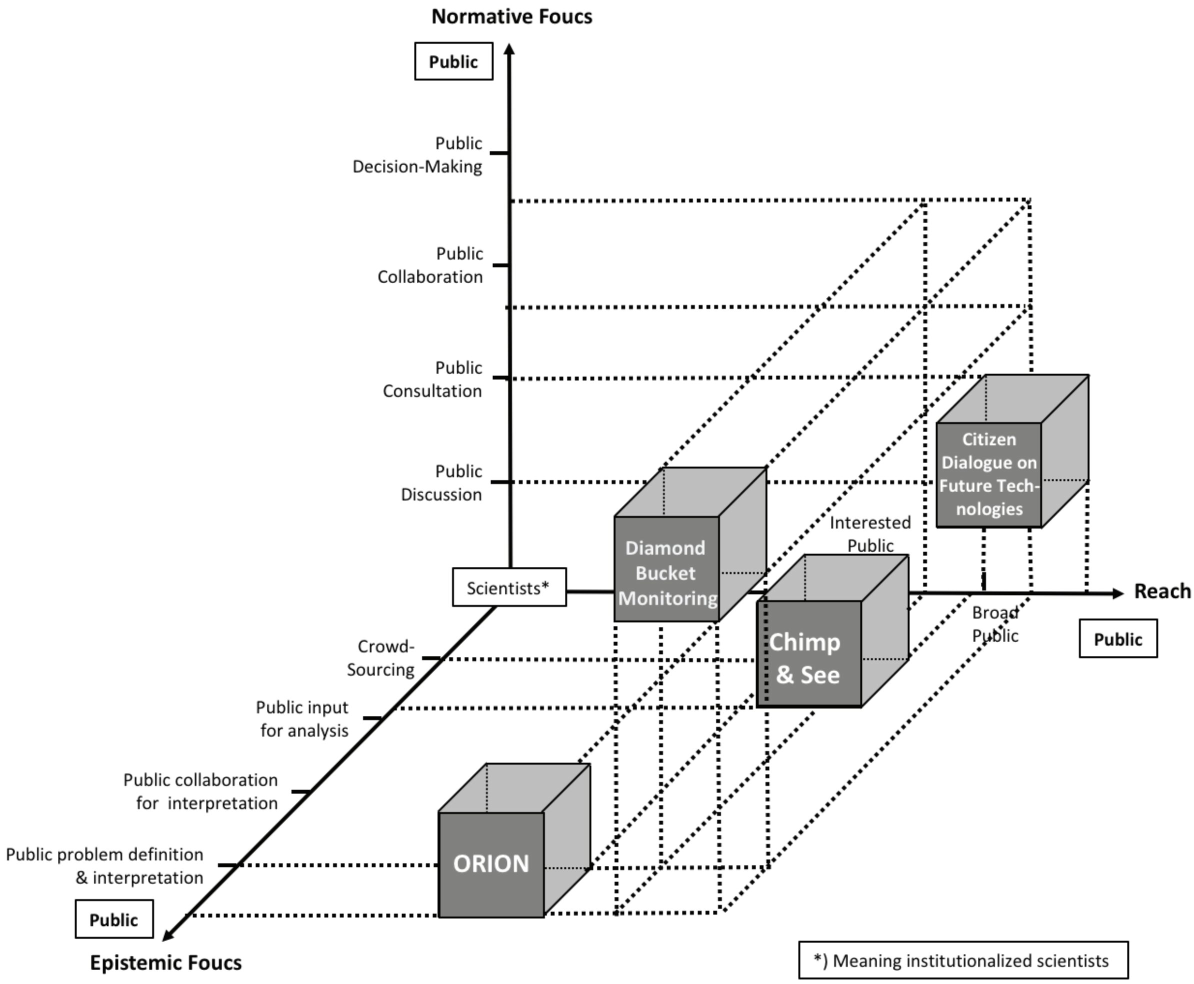

Figure 4: The participatory science cube with four example projects: "chimp&see" as a typical scientific crowdsourcing project, the citizen dialogue on future technologies as a public consultation on science policy, the activities of the ORION entomological society as scientific work conducted by researchers in a civil society organization and the Diamond bucket monitoring as an example of effective science activism.

Conclusion

In this article, we have argued for a holistic discussion of participation in science, bringing the two established academic silos of participatory, deliberative science governance and citizen science together. We have reviewed the existing models and typologies for participatory governance and citizen science and found that each of them looks almost exclusively at a single dimension while leaving out other dimensions. Therefore, we have looked for multi-dimensional frameworks for participation and found Archon Fung`s (2006) three-dimensional 'democracy cube' for participatory governance. After reviewing the 'democracy cube', we proposed an expanded 'participatory science cube' as an adaptation of the original model. The participatory science cube includes two axes building on the two core dimensions of deliberative participation and citizen science – the balance of the normative and epistemic focus between the public and scientists. The third axis shows the dimension of reach with regard to participating actors. We have shown how prototypical scientific approaches as well as concrete case studies fit into the cube and discussed the possibilities and limitations of its use.

For the participatory science cube, the academic saying: "Essentially, all models are wrong, but some are useful" (Box and Draper, 1987: 424) holds true. As presented here, the participatory science cube can serve as a model incorporating different forms of participation, from dialogue about science governance to actual participation in research processes. This model can be used to assess, compare and discuss different participatory approaches. However, it cannot cover individual experiences and reflect the various normative judgements on how participatory science ought to be done. Being aware of the limitations of the model, we hope to have presented a useful and accessible tool for a comprehensive discussion of the various ways of participating in science.

The democracy cube was developed as a descriptive typology, but discussions around citizen science and participation in science are often led by normative arguments, calling for a maximum degree of openness, inclusion and empowerment of non-traditional participants. And indeed, there is a large opposition to new approaches to scientific inquiry and participatory decision-making within traditional scientific institutions. Therefore, we strongly support the push towards a more open and inclusive governance and conduct of research. We hope that the 'participatory science cube' can be a helpful tool for the many discussions which need to be had to achieve this. But we also want to highlight that for us, *every* form of participations has its justification. As Barbara Prainsack (2014: 155) has stated: "we should not assume […] that all those who participate in projects where participants have only limited influence in project design are being exploited. For many, being part of something useful, being acknowledged publicly in publications, or learning about the scientific area in question is enough of an incentive to participate, and a satisfactory reward". For our understanding of the proposed 'participatory science cube' this means that there is no normative mandate to push all participatory approaches to the outermost corner of maximum openness, as long as the purpose, design, guidelines and limits for participatory projects are transparent, fair and clearly communicated to participants and the public.

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Notes

1) Further evaluation tools based on the quality of participation, exchange, and outcomes are presented by Tippett et. al 2007 and Lynam et al. 2007.

2) For this article and the proposed framework, 'scientists' refers to 'institutionalized scientists, professionally operating in the hierarchy of typical science organizations'. This would be 'normal science' or 'mode-1' science: idealized, disciplinary "pure" science independent of outside influence. The opening of science in general (towards a post-normal, mode-2, transdisciplinary, … science (compare Funtowicz and Ravetz 1995, Nowotny et al. 2003 and Hirsch Hadorn et al. 2008) and the subsequent new definition of the understanding of science itself would be reflected by a shift within the framework.

3) Disclosure: One of the authors, Philipp Schrögel, was involved in the planning and implementation of the dialogue process.