Researchers and citizens on par:
Challenges and platform-based solutions to transitioning to co-created citizen science

Master Thesis

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Abstract

Purpose: Most current citizen science projects limit citizen involvement to few research phases, mainly data collection, and sometimes analysis or dissemination activities. Although co-created citizen science projects, in which citizens are encouraged to take part in all phases of the research process, promise many benefits, they are quite rare in practice due to several barriers. These barriers as well as solutions to overcoming them have received little attention in the academic literature. This thesis explores these barriers and argues that stakeholders in citizen science, and particularly online platforms, that contribute to realizing a citizen science project, could provide solutions to overcoming these barriers.

Study design: The authors conducted an exploratory qualitative inductive-deductive multiple case study, based on three steps: First, to inspire the further analysis, the authors reviewed the existing citizen science and platform literature and developed a theoretical framework of known barriers and platform-based solutions to citizen science. Second, the authors identified barriers to transitioning to co-created citizen science by conducting a qualitative analysis of sixteen citizen science projects of six different sample groups. Third, potential platform-based solutions that could mitigate and remove barriers are suggested based on a qualitative analysis of seven platform types, derived from a total sample of 33 online platforms.

Findings: We identified five types of barriers hindering researchers to transition to co-creation: Barriers of (1) will and (2) ability of the researcher, (3) barriers of ability of the citizen, (4) barriers to citizen engagement and team development, and (5) bureaucratic and administrative barriers. Most individual online platforms provide limited help to remove these barriers. However, a combination of the services and features of several platforms provide ample support for project implementation.

Theoretical implications: This thesis contributes to growing body of literature that suggests that each type of citizen science project comes with benefits and challenges. It shows that barriers to co-created projects need to be addressed differently than those of citizen science.

Practical implications: This thesis is relevant to practitioners as it addresses the current public discourse around the democratization of science. It is also useful for citizen science project owners and citizens because it increases awareness about possible pitfalls and hurdles in realizing a successful co-created citizen science project, providing practical tools (i.e. online platforms) that can facilitate projects.

Originality: Scarce literature exists on the challenges related to higher forms of citizen science. This study offers a comprehensive analysis of barriers to co-created citizen science, by considering factors that influence a) expanding the number of tasks that citizens conduct and b) co-decision making. It applies a unique solution-oriented approach by conducting a first systematic analysis of different online platforms that could facilitate co-created citizen science.

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2. Introduction

Scientific research has been the realm of universities and other academic institutions, government laboratories, and corporations' R&D for many years. For much of the nineteenth century and until the early twentieth century, scientific autonomy was considered the best way to ensure high-quality research, and as a result, the general public (also referred to as non-scientists or citizens) were largely removed from the scientific process. If citizens were involved in science, the involvement was characterized by a clear division of roles between researchers and citizens. Researchers were considered superior knowledge generators with decision making authority, whereas citizens were perceived as "amateurs" who could engage in simple data collection tasks at most (Eitzel et al., 2017).

This resulted both in the development of an increasing gap between lay and expert knowledge and an increasing misalignment between scientific and social interests (English, Richardson, & Garzón-Galvis, 2018a; Lengwiler, 2008; Michael J. O. Pocock, Tweddle, Savage, Robinson, & Roy, 2017). Criticism of the traditional science system has grown (Guston, 2007) and politicians have questioned the integrity and productivity of science. Several scholars have called for more 'Open Science', that allows for an increased transparency and connectivity between science and public domains by allowing for a broader public participation in research (Deutsche Forschungsgemeinschaft (DFG), 2017).

In an attempt to addressing these misalignments, several scholars have promoted the avenue of citizen science which refers to the voluntary and intended engagement of non-scientists / citizens into the scientific research process is increasingly being accepted and applied by scientists (Follett & Strezov, 2015; Michael J. O. Pocock et al., 2017). A prominent example of a citizen science project is the astronomy project "Galaxy Zoo" in which citizens are invited to inspect and classify images of galaxies. Another popular project is "eBird" in which citizens citizens monitor and report images and locations of wild birds (Franzoni & Sauermann, 2014a). While historically citizens were only involved in data collection, recently scientist shifted towards including citizens in a more diverse set of tasks and other steps of the research process (Follett & Strezov, 2015; Michael J. O. Pocock et al., 2017). Nevertheless, public involvement is still commonly limited to data collection, and sometimes analysis or dissemination activities. Arguing that classic citizen science projects do not fulfill the goals of citizen science, a number of scholars have called for deeper citizen participation. Taking a "participatory turn" in science, they demand that public participation reaches beyond the classic lower form of citizen science activities to include, at least in the long-term, also the more complex phases of research process such as the formulation of a research question or the development of a research design (Deutsche Forschungsgemeinschaft (DFG), 2017). The idea is to democratize science by giving citizens the opportunity to co-create (i.e. the act of creating together) research with scientists in projects in which task completion and decision-making authority is shared in an equal partnership (i.e. co-created citizen science projects) (Deutsche Forschungsgemeinschaft (DFG), 2017; Haklay, 2013; Toogood, 2013).

Although co-created citizen science projects promise many benefits, they are not as frequently applied as one might think. Co-created citizen science projects are found to include greater learning and sense of ownership of citizens, the development of novel and creative research questions, and increase of collective capital (Beck, Grimpe, Poetz, & Sauermann, 2019; Corburn, 2007; Liebenberg et al., 2017; Pettibone, Vohland, Bonn, Richter, Bauhus, Behrisch, Borcherding, Brandt, Bry, Dorler, et al., 2016). However, co-created projects, the highest form of researcher-initiated citizen science are rare despite their potential benefits (Cohn, 2008a; Crowston, Mitchell, & Østerlund, 2018a). This suggests that there are challenges related to transitioning from lower forms of citizen science to higher forms, and particularly co-created citizen science.

The literature outlines some barriers to citizen science in general and to lower forms of citizen science however lacks comprehensive understanding of barriers to higher forms (Crowston et al., 2018a). For example, researchers raised concerns about the validity of data collected or analyzed by citizens (Follett & Strezov, 2015). Additionally, scholars have suggested that each type of citizen science project comes with benefits and challenges, and that the costs could outweigh the benefits in some projects (Franzoni & Sauermann, 2014a; Susanne Hecker, Bonney, et al., 2018). However, the literature offers only a few explanations (e.g. challenges that may result from the complexity of the tasks) as to why researchers who are already conducting citizen science projects are not transitioning to higher forms of citizen science (Susanne Hecker, Bonney, et al., 2018). Another aspect that is hardly covered in the literature is the role of stakeholders in citizen science projects (Göbel, Martin, & Ramírez-Andreotta, 2017). A citizen science stakeholder is an "individual or organization that contributes to realizing a citizen science project, has a vested interest in a citizen science project, and/or benefits from the research activities and data produced" (Göbel et al., 2017). Such stakeholders range from government agencies, academic and research organizations to global and national citizen science associations and online platforms, among others (Göbel et al., 2017). While the role of some stakeholders such as citizen science associations has already been investigated (e.g. Hecker et al., 2018), the role of different online platforms in facilitating (co-created) citizen science has been given little attention. Platforms refer to a "distinct mode of organizing production and exchange" (K. Boudreau, 2017), which enables value-creating interactions between different actors (Kohler & Chesbrough, 2019).

Lastly, the literature does not place each platform into a broader context of existing platforms and does not provide a systematic and comparative analysis of platforms in relationship to co-created citizen science. Researchers have investigated the role of technology in citizen science (Brenton, von Gavel, Vogel, & Lecoq, 2018; Mazumdar et al., 2018), analyzed distinct platforms such as systematic review platforms (Strang & Simmons, 2018), and provided case based examples of crowdsourcing platforms for citizen science (Lichten, Ioppolo, D'Angelo, Simmons, & Morgan Jones, 2018). However, diverse online platforms could help mitigate or remove barriers to transitioning to co-created citizen science.

These range from platforms that allow hosting and finding citizen science projects (e.g. Zooniverse), to labor market platforms (e.g. Amazon MTurk), or crowdsourcing (contest) platforms such as InnoCentive (Lichten et al., 2018), among others. Some platforms offer solutions e.g. training to the crowd or offering quality assurance mechanisms (Franzoni & Sauermann, 2014a). However, it is likely that more permanent barriers (e.g. incentive systems in science) are not easily addressed by online platforms.

Based on the above considerations, the authors set out to answer the following research question:

What are the barriers to transitioning to co-created citizen science and how can online platforms help overcome these barriers?

The purpose of this thesis is to investigate a topic that has received very limited attention in the academic literature, advance theoretical explanations and build theory for an understudied phenomenon, laying the groundworks for further deductive investigations (Bingham & Eisenhardt, 2011). To address the research question and fulfill the research objective, the authors conducted an exploratory qualitative inductive-deductive (abductive) multiple case study using a three-step approach. First, to inspire further analysis, the authors reviewed the existing citizen science and platform literature and developed a theoretical framework of known barriers and platform-based solutions. Second, the authors identified barriers to transitioning to co-created citizen science by conducting a qualitative analysis of a heterogeneous sample of six different citizen science project types, consisting of sixteen citizen science projects. Third, potential platform-based solutions that could mitigate or remove barriers were identified based on a qualitative analysis of seven platform types, derived from a total sample of 33 online platforms. The final result is an abductively developed framework of barriers and platform-based solutions to transitioning to co-created citizen science.

The study takes place in the citizen science context in Europe, North America, and Oceania. Greater emphasis is placed on Europe due to the existence of a large quantity of European citizen science platforms that allow for an ease of access to study participants. The study is delimited to ‘crowdsourced citizen science projects’ in which the citizen science activity is initiated by researchers. Among the crowdsourced citizen science projects are citizen science projects from various disciplines, ranging from those in which citizen science is common (e.g. biology), to those in which it is uncommon (e.g. medicine). Projects that differ in project duration, funding, scale, and scope are considered. The analysis of bottom-up, citizen-led initiatives is not within the scope of this thesis.

In terms of research perspective, this study favors the researchers’ perspectives of barriers to transitioning to co-created citizen science. The perspectives of non-researcher project coordinators and platform stakeholders are valued to shed light on barriers, but to a lesser extent. Their perspective carries greater weight in shedding light on platform-based solutions. Due to time constraints, the perspective of citizens is not within the scope of this thesis.

While the analysis of different stakeholders could be interesting for future research (Göbel et al., 2017), the analysis in this thesis focuses on online platforms. Here, the aim is not to be exhaustive in describing a full set of platforms available to project owners and citizens. Platforms that do not facilitate the pursuit of co-created citizen science projects are not considered. For example, platforms that only enable citizens to fulfill a certain (simple) task such as transcription of audio or text are excluded. Further, this thesis bundles different platforms into distinct platform types, such as project hosting and crowdsourcing (contest) platforms that share similar characteristics. Although the authors recognize that distinctions within platform categories may exist, the analysis of these distinctions is not within the scope of this thesis. The thesis then performs a comparative analysis of the platform types with regards to the solutions they offer for co-created citizen science (e.g. similar to Felin & Zenger, 2014).

This thesis aims to make several theoretical contributions. First, it contributes to the existing literature on citizen science, collaborative research, and public participation in science by providing new evidence for challenges faced in different types of citizen science projects. Second, it expands the existing literature by analyzing an understudied phenomenon, i.e. the low adoption of co-created citizen science projects. Third, it unravels the factors that impact transitioning to higher forms of citizen science, including created citizen science. This is done by distinguishing between factors that influence (1) the number and type of citizen-tasks and (2) co-decision-making in citizen science projects. Fourth, it also provides reasons as to why co-created citizen science projects are uncommon. Finally, this thesis expands on the existing literature by applying a unique solution-oriented approach, conducting a first systematic analysis of different online platforms that could facilitate co-created citizen science.

In addition to contributing to the academic literature, this thesis is also relevant to practitioners as it addresses the current public discourse around the democratization of science (Deutsche Forschungsgemeinschaft (DFG), 2017). First, it is relevant to the public at large, as it sheds light on the current challenges of broader public involvement in the research process and suggests solutions to making academic research more useful for society. Second, it is relevant to citizen science project owners and participating citizens as it increases awareness about possible pitfalls and hurdles in realizing a successful co-created citizen science project, as well increase awareness of mechanisms and practical tools (i.e. online platforms) that can facilitate overcoming these. Finally, this study can also benefit platform providers because it detects benefits and limitations, and suggests areas for new development.

This thesis is structured hereafter as follows (cf.

Table 1). Chapter 2 provides background literature on open science, citizen science, and platform-based organizations. Important terminology is introduced. Chapter 3 presents a conceptual framework derived from the literature, by presenting known barriers and platform-based solutions. Subsequently, chapter 4 outlines the methodology of this study. Chapter 5 presents the results of the analysis. The final chapter 6 reflects on the research question, derives theoretical and practical implications, highlights study limitations, and presents recommendations for future research.

(1) Introduction	(2) Background literature	(3) Literature review
• Introduction to the topic • Research question • Delimitations • Relevance	Open science • Open science vs. citizen science Citizen science • Crowdsourced citizen science • Typologies of citizen science • Trends in citizen science • Benefits of different forms of citizen science Platform-based organizations • Platform-based organizations • Platforms in citizen science	Barriers and platform-based solutions to transitioning to co-created citizen science • Individual (researcher) level • Individual (citizen) level • Project level • Organizational level • Ecosystem level
(4) Methodology	(5) Results	(6) Discussion
• Research design • Data sampling • Data collection • Pilot testing • Data analysis	• Results on barriers and solutions from the empirical study	• Findings • Implications • Limitations • Avenues for future research • Conclusion

Table 1: Structure of this thesis

3. Background Literature

To build the theoretical foundation of this study, this chapter places this work in the existing literature. Key terms are defined to prevent misconceptions that may emerge from a lack of a common understanding in the field of citizen science (Shaw, Draux, García Martín, Martin, & Bieling, 2017). The chapter is structured as follows. First the concepts of 'open science' and 'citizen science' are presented and distinguished from each other. This is followed by an overview of the concept of 'crowd-sourced citizen science' which frames this study. Then, various typologies of citizen science are touched upon and the one used in this study elaborated on. The following section focuses on trends in citizen science and shows that certain types of citizen science projects, i.e. co-created projects, are currently underrepresented. The next section outlines the benefits of citizen science projects. The chapter continues with theory on platform-based organizations and finishes with platforms in citizen science.

3.1 Open Science vs. Citizen Science

This section places this study in the existing literature. It is shown that citizen science presents a stream of open science and highlights that the concepts are related but not identical.

"Open science" is "transparent and accessible knowledge that is shared and developed through collaborative networks" (Vicente-Saez & Martinez-Fuentes, 2018). It means that research is openly conducted, and research contributions are publicly accessible (Vicente-Saez & Martinez-Fuentes, 2018). The "open science" movement encompasses several trends (Franzoni & Sauermann, 2014), which range from open access, open code, or open peer review in research to the public participation in scientific projects (i.e. citizen science) (Vicente-Saez & Martinez-Fuentes, 2018). A dominant and proliferating stream of open science is "citizen science". The literature describes citizen science as the voluntary and intended engagement of non-scientists (commonly referred to as the "crowd", "citizen scientists", "amateur scientists", "volunteers", or the "public") into the scientific research process. In this regard, the scientific work is often undertaken in collaboration with or under the direction of professional scientists and scientific institutions (Edwards, 2014; Pocock et al., 2017; Welvaert & Caley, 2016). It is said that the aim of citizen science is to democratize science to make it more relevant to the general public (Deutsche Forschungsgemeinschaft (DFG), 2017).

In the literature, the terms "open science" and "citizen science" are oftentimes used interchangeably, along with other terms such as "crowd science", "participatory science", "crowdsourced science" or "networked science" among others (English, Richardson, & Garzón-Galvis, 2018b; Franzoni & Sauermann, 2014a; Kullenberg & Kasperowski, 2016; Welvaert & Caley, 2016). While possible to place citizen science into the broader trend of open science, this paper distinguishes citizen science from open science. Whereas open science requires an open participation and public disclosure of intermediate inputs, citizen science does not have to disclose intermediate inputs publicly (Franzoni & Sauermann, 2014; Wiggins & Crowston, 2011). To conclude, open science and citizen science are related, but the terms should not be used interchangeably.

3.2 Crowdsourced citizen science

Similar to a lack of clarity with respect to the use of the terms "open science" and "citizen science", the literature lacks a common understanding and definition of public participation in the scientific field (Franzoni & Sauermann, 2014a). To clarify the understanding of citizen science in this thesis, the following section elaborates on the concept of "crowdsourced citizen science". The understanding of citizen science in this thesis is framed by this concept.

Scientists in the field of citizen science have suggested that citizen science represents "a form of crowdsourcing applied to science" (Wiggins & Crowston, 2011a). From an innovation perspective, crowdsourcing is the act of "*outsourcing* a *task* to a "*crowd*" rather than to a designated "agent" (Afuah & Tucci, 2012). It is usually enabled through *digital means* and involves *broadcasting* a task via a *flexible open call* to an unknown crowd, who will voluntarily undertake the task (Estellés-Arolas & González-Ladrón-De-Guevara, 2012). Applying this concept to the field of citizen science, this thesis refers to "crowd-sourced citizen science" as a *collaborative approach* that is initiated via an *open call* in which a *crowd participates* in some or all phases of the *scientific research process*. Similar to crowdsourcing projects in innovation, crowdsourced citizen science projects should contain the following characteristics (Estellés-Arolas & González-Ladrón-De-Guevara, 2012):

(1) *Crowdsourcer:* The activity is initiated by professional researcher(s).

(2) *Crowd:* The crowd consists of multiple contributors who are members of the general population, i.e. they are not scientists by profession (Sauermann & Franzoni, 2015). The crowd has general and/or specific knowledge (i.e. lay expertise; Prior, 2003) that is based on previous education and/or experience in the same, related or unrelated subject field). Depending on the (knowledge) requirements of each research process phase, the individual members of the crowd may change (Franzoni & Sauermann, 2014a).

(3) *Task (i.e. scientific research process):* The project conducted must have a scientific outcome. That means that the task performed by the crowd can entail the completion of one or more of the steps of the empirical research process or it can entail completing a part of one or more of the steps of the process.

    This characteristic excludes projects in which collected data is not used for scientific purposes. This often includes pure education or outreach projects (Hecker et al., 2018). Projects in which citizen are only informed about the project and its results, or in which citizens are merely consulted for their opinion by researchers (cf. Arnstein, 1969) are also excluded. In these cases, the crowd is not completing a task but is rather providing advice.

    The empirical research process, in which the task is embedded, generally consists of five important phases: 1) conceptual, 2) design & planning, 3) empirical, 4) analysis, 5) writing, 6) dissemination (Beck et al., 2019; Cooper, Dickinson, Phillips, & Bonney, 2007; Dickinson et al., 2012a; English et al., 2018b; Follett & Strezov, 2015; Lichten et al., 2018).

(4) *Collaborative approach:* During the research process, the crowdsourcer and the crowd will jointly produce the research outputs. The crowd can either perform tasks together with researchers or conduct research independently if this contributes to an integrated whole. Also, projects must be based on a dyadic beneficiary relationship between the parties (Dick, 2017;

Estellés-Arolas & González-Ladrón-De-Guevara, 2012; Franzoni & Sauermann, 2014a).

(5) *Participation*: Participation means that the crowd *actively* contributes to the task completion by using their cognitive abilities and/or knowledge assets. Our understanding of participation thus excludes passive forms such as those in which the crowd supplies computing power to the researchers or carries sensors to collect data for scientists (Haklay, 2013).

(6) *Open call:* An open call of variable extent is used to reach the crowd. This means that a problem or task is broadcasted to the crowd whose members choose themselves to participate in the research project (i.e. self-selection). In comparison to crowdsourcing literature, the definition used in this thesis does not necessarily include an online element, as some research stages such as defining the research question benefit closer proximity of the crowd members to foster creativity and enable debates (Senabre, Ferran-Ferrer, & Perelló, 2018). Thus, online crowd participation may not be purposeful throughout all research stages.

To conclude, citizen science in this thesis represents a form of crowdsourcing applied to science.

3.3 Typologies of citizen science

In this section, typologies of citizen science are touched upon. Then, the typology used in this thesis is explained to clarify the terminology of this thesis.

Several scholars have attempted to describe the diversity of projects placed under the umbrella term "citizen science", arguing that public participation in research is not one single phenomenon (Schäfer & Kieslinger, 2016a). Different typologies of citizen science projects exist (English et al., 2018). Researchers have based their typologies on research project characteristics. Many scholars distinguish projects based on the type of task performed by citizens and/or the level of engagement of citizens in each stage of the research process (Bonney et al., 2009; Cooper et al., 2007; English et al., 2018; Dickinson et al., 2012; Haklay, 2013). Other scholars propose typologies based on the purpose of the project (e.g. Wiggins & Crowston, 2011) the scientific field of the project (Pocock et al., 2017; Follett & Strezov, 2015), the structure of the project (Welvaert & Caley, 2016), the locus of knowledge production (Schäfer & Kieslinger, 2016b), and the attribution of expertise (Dickel & Franzen, 2016). It shows that citizen science is a broad and heterogeneous activity that incorporates many forms of public participation in science.

The typology of projects used in this thesis builds on a common typology coined by (Bonney et al., 2009). It distinguishes between "contributory", "collaborative", and "co-created" citizen science projects, based on the degree of participation and amount of control given to citizens in the scientific research process.

Contributory projects represent the lowest form of projects. These projects are designed and driven by researchers, and citizens are involved only in few research phases, mainly in data collection, and sometimes in analysis or dissemination activities. In these projects, citizens do not exert control as they do not determine any of the research process steps(Bonney et al., 2009). Several researchers who have proposed alternate typologies have used various terms to refer to projects that are largely congruent with contributory projects, such as the citizen science research model (Cooper et al., 2007); and crowdsourcing (English et al., 2018), distributed intelligence (Haklay, 2013). "Investigation projects" that engage citizens in data collection activities mostly in the field of ecology and "virtual projects" that are similar to investigation projects but entirely ICT mediated (Wiggins & Crowston, 2011), and the "community workers model" where citizens collect samples and analyze data (Wilderman, 2007) would also fall into this category.

In collaborative projects, scientists generally design the study, and citizens assist in multiple research activities (Bonney et al., 2009). They typically collect data for scientists and may help analyze samples and data, interpret the data, draw conclusions and disseminate the results. In few instances, they also help to refine the study design and methods (Bonney et al., 2009). Researchers have used other terms, e.g. "community science" (Haklay, 2013) to refer to these types of projects.

Co-created projects represent the highest form of projects where citizens are encouraged to take part in all phases of the research process, from formulating the problem to disseminating the results (Bonney et al., 2009). Oftentimes, citizens come up with a research question and then scientists and citizens work together to answer it. Working on par with scientists, the citizens exert significant control over the project (Bonney et al., 2009). Scholars have used other terms to describe what Bonney et al. (2009) term co-created projects. These terms include "extreme citizen science" (English et al., 2018), "collaborative science" (Haklay, 2013), or "participatory action research" (Cooper et al., 2007) among others.

Building on the typology of citizen science outlined above, this thesis distinguishes projects based on the number of activities citizens are actively engaged in, and the level of control they exert. Control is defined by decision-making responsibilities that citizens receive throughout the scientific process. In this thesis, classic (contributory) citizen science refers to projects in which the crowd is involved in only few research phases, typically data collection, and does not receive any decision-making responsibilities. Collaborative citizen science refers to projects in which the crowd is involved in several research phases and receives (some) decision-making responsibilities in some research phases. Co-created citizen science refers to projects in which researchers and the crowd work on eye-level with each other, sharing decision rights in an equal partnership throughout all research phases.

It should be noted that this thesis does not consider certain more extreme projects co-created projects. Projects in which citizens initiate and drive the project and take decisions independently in one or several research phases are excluded. Such projects represent a more extreme form of citizen science because citizens lead the process and scientists act as advisors or facilitators (Cohn, 2008; Pocock et al., 2017; Prestopnik, Crowston, & Wang, 2017; Welvaert & Caley, 2016). These citizen science projects have been called "extreme citizen science" (Haklay, 2013), or "collegial projects" if they address a scientific question (Dickinson et al., 2012; Schäfer & Kieslinger, 2016), "action research" if the research is conducted to intervene in topics that cause local concern from the bottom-up (Wiggins & Crowston, 2011; Schäfer & Kieslinger, 2016), or "community-based, participatory research" (Wilderman, 2007)To conclude, the typology of projects used in this thesis distinguishes between "contributory", "collaborative", and "co-created" citizen science projects, as coined by Bonney & Ballard et al. (2009).

3.4 Trends in citizen science

In the following, recent trends in citizen science are presented to show how the citizen science field is changing.

A first trend is that scientists increasingly accept and apply citizen science (Follett & Strezov, 2015; Pocock et al., 2017). Gradually, citizen science is being recognized as a distinct field of research (Jordan, Crall, Gray, Phillips, & Mellor, 2015; Haklay, 2013), and the amount of literature published in the field is growing. While the term citizen science was already used in the literature 1990s, its use has increased drastically in the last decade with the open science movement (Follett & Strezov, 2015; Trumbull, Bonney, Bascom, & Cabral, 2000). Today, the literature covers a broad range of contents, ranging from general articles on citizen science or specific projects to articles addressing concerns of scientists (Follett & Strezov, 2015). With many concerns being addressed (while some concerns of course remain), the number of citizen science projects has grown (Bonney et al., 2014b) across a number of disciplines. Historically citizen science was used in the environmental domain in which mostly longitudinal or dispersed data is necessary to conduct studies (Welvaert & Caley, 2016; English et al., 2018). Today, researchers in a broad range of disciplines are engaging in citizen science. While citizen involvement today is still most common in the research field of biology and ecology, other fields such as medicine or social sciences have started to invite non-scientists to contribute to research more and more (Follett & Strezov, 2015).

Another trend is that projects are taking a different form than in early citizen science projects (Follett & Strezov, 2015). An increasing amount of citizen science projects uses computer technology and technological innovation to contribute to research (Pocock et al., 2017), and this trend is expected to continue (Follett & Strezov, 2015).It is said that citizens could receive more freedom in the future as a result of this. Web-based platforms for example enable that volunteers decide when and where to conduct research and then report the findings online (Follett & Strezov, 2015; Welvaert & Caley, 2016). This points to the importance of online platforms as facilitators of citizen science. Online platforms are elaborated on in section 2.6 and 2.7.

Another change is that the activities that citizens are involved in are broadening. Historically, citizen science projects included (offline) data collection activities only. Typically, local hobbyists engaged in monitoring of various species, oftentimes birds (Dickinson, Zuckerberg, & Bonter, 2010a). Such projects typically fell into the categories of classic (contributory) citizen science. Today citizen science projects are more diverse (Follett & Strezov, 2015; Pocock et al., 2017), Scientists engage volunteers in several phases of the research process, not only in data collection. However, most current cases limit public involvement to simple data collection, and sometimes coding, processing, or analysis tasks. The projects typically range from classic (contributory) to collaborative citizen science (Cohn, 2008; Pocock et al., 2017; Prestopnik et al., 2017; Welvaert & Caley, 2016; Ballard, Phillips, & Robinson, 2018). Only few current projects fall into the co-created project category, as only few projects *also* involve the crowd in the more complex phases of the research, e.g. the formulation of a research question, the development of a research design, or the study dissemination (Cohn, 2008; Crowston et al., 2018; Pocock et al., 2017; Prestopnik et al., 2017; Welvaert & Caley, 2016).

With this in mind, a number of scholars are calling for deeper citizen participation. They demand that, at least in the long-term, citizens participate in the whole research process (Deutsche Forschungsgemeinschaft (DFG), 2017; Newman et al., 2012; Stevens et al., 2014). The general argument is that classic (contributory) citizen science does not democratize science as it represents a "minimalist" form of participation. Scientists would answer the calls for greater transparency and accountability of science only when the public is included in decision-making processes (Jasanoff, 2003). Recent discussions center around the principle of ensuring the *opportunity* for citizens to participate (rather than actual participation) in various stages of the research processes (Ballard et al., 2018). This group of researchers acknowledges that not all participants have the desire to be highly engaged in all research phases (Phillips, Ballard, Lewenstein, & Bonney, 2019), and recommends that participants choose their level of participation according to their needs, rather than researchers presuming levels of interest (Hecker et al., 2018; Haklay, 2018). The scholars argue that no one form of engagement is best, underscoring the potential benefits of all forms of citizen science projects (Haklay, 2018; Ballard et al., 2018; Pettibone et al., 2018).

To summarize, the citizen science field is evolving, citizen science is becoming more accepted and projects are increasingly taking different forms. While projects are becoming more diverse, higher forms of citizen science remain rare, despite the potential benefits they bring.

3.5 Benefits of different forms of citizen science

As outlined in the previous section, the citizen science community currently underscores the benefits of various forms of citizen science. To better understand the current state of the research, the benefits are presented in this section.

Early citizen science publications emphasized the advantages of (classic) citizen science compared to traditional science approaches. Data collection and data processing capabilities were described as core advantages of citizen science projects (e.g. Michener, n.d.; Franzoni & Sauermann, 2014; Dick, 2017). Researchers found that citizen science can often operate on greater scales (e.g. geographic) and over longer time periods than traditional science (McKinley et al., 2017a). By using a large crowd of participants, citizen science offered a cost-effective way to collect data at a massive scale and process data fast (Wiggins & Crowston, 2011; Liebenberg, 2013). Further literature cites an increased research capacity (e.g.(Den Broeder, Jeroen Devilee, Van Oers, & Wagemakers, 2016)) as a benefit. Researchers increasingly face barriers due to more complex and intertwined problems and phenomena (Michener, n.d.), and by drawing on the diverse knowledge or specialized skill sets of the volunteering crowd (e.g. Rosenberg, 1982), citizen science projects facilitate solving such problems (Wiggins & Crowston, 2011; Franzoni & Sauermann, 2014). Other researchers allude to an increased chance of serendipitous discovery in citizen science (Woodcock; Greenhill, Anita;Holmes, Kate; Graham, Gary;Cox, Joe;Masters, 2017; Lintott et al., 2009; McKinley et al., 2017). Raddick et al., (2010) for example report the discovery of an unusual object by a teacher who was classifying galaxies in the Galaxy Zoo project.

Beyond these methodological and resource-based benefits, scholars have also identified benefits for citizens who participate in citizen science projects. Citizens participate in citizen science projects for various reasons, satisfying intrinsic and extrinsic motives (Marjanovic et al., 2012; Rotman et al., 2014; Raddick et al., 2010). Studies suggest that many citizens are motivated by the opportunity to create a public good, to contribute to the societal benefit (i.e. knowledge) (Marjanovic et al., 2012) and to real science (Raddick et al., 2010; Rotman et al., 2014). Some citizens even show so much enthusiasm for the research that they decide to pursue science- or management-related careers (Johnson et al., 2014). It is often claimed that participation in science has educational benefits for participants, such as an increase of the understanding of the scientific research process (Trumbull et al., 2010; Brossard et al., 2005), an increase in knowledge of the subject field (Brossard et al., 2005), or an increase of the scientific literacy (Cronin & Messemer, 2013; Bonney & Ballard et al., 2009; Shaw et al., 2012). The educational benefits of citizen science are however still being tested (Cronje et al., 2011; Merenlender et al. 2016; Phillips, 2017).

An overarching theme is the role of citizen science in democratizing science (Hecker, Bonney et al., 2018). It has been argued that the engagement of non-scientists into the scientific research process reduces the gap between scientific and public fields by providing a greater alignment of scientific and social interests (Pocock et al., 2017; English et al., 2018). Finally, citizen science is said to empower the public to engage in policy and decision-making processes and spark change (English et al., 2018).

While the above benefits primarily refer to classic (contributory) citizen science, the citizen science community has also recognized numerous potential benefits of involving the public more deeply in scientific research (Robinson et al., 2018, in Hecker & Haklay, 2018). Scholars generally agree that deeper forms of participation can open doors to a broad range of benefits (Robinson et al., 2018; Shirk & Ballard et al., 2012). Following Danielsen et al. (2012), Shirk & Ballard et al. (2012), through empirical syntheses and case studies, show that project outcomes tend to relate to the degree of participation of citizens. For example, compared to collaborative and classic (contributory) projects, co-created citizen science projects have a higher potential for enhancing citizens' capacities, e.g. science process skills (Danielsen et al., 2009), have a higher potential for changing social-ecological systems (Danielsen et al., 2009), and create outcomes that are more aligned with societal concerns (Wilderman et al., 2004; Novak et al., 2018, in Hecker & Haklay, 2018). Many scholars come to the conclusion that co-created projects allow for more intensive involvement in local policy issues and ensure that local communities' needs, knowledge, and viewpoints are represented (e.g. Ballard et al., 2018, in Hecker & Haklay, 2018; Corburn, 2007; Stevens et al., 2014). Additional benefits associated with co-created citizen science are a greater sense of ownership of participants (Coburn, 2007) and better learning (Novak et al., 2018, in Hecker & Haklay et al., 2018; Raddick et al., 2010).

While the above benefits result from involving citizens in activities and decision-making across multiple research phases, some benefits result from deeper public involvement in specific research phases. In this regard, much of the literature identifies benefits associated with public involvement in the conceptual stage of research. Co-creating in this research phase uses the collective intelligence of the crowd. Through the exchange of ideas and the recombination of broader knowledge, novel and creative research problems and questions can be formed (Beck et al., 2019). Co-creation in the conceptual phase can also set new directions for science that are considered relevant and useful to the broader public (Hinchliffe, 2014; Shirk & Bonney, 2018, in Hecker & Haklay, 2018; Villarroel, 2014). Citizens hold insights that researchers generally do not have access to (Villarroel, 2014; Shirk & Bonney (2018), in Hecker & Haklay, 2018), for example experiential knowledge that citizens gain through experiences in everyday life. Including such knowledge early on sparks new scientific knowledge previously not addressed (Shirk & Bonney, 2018, in Hecker & Haklay, 2018). In addition to research that outlines benefits related to a deeper involvement in the conceptual phase, some research suggests additional benefits related to other phases. For example, involving citizens in the design and planning phase of research creates transparency and trust (Rutten, Minkman & van der Sande (2017). Involving them in the analysis phase could help scientists analyse and interpret results from unusual data (Ballard and Huntsinger, 2006; Haberl et al., 2006; Huntington, 2000; Laidler, 2006), or educate and empower them to critically reflect on the relevance and validity of the research (Lidskog, 2008). Moreover, involving citizens in the writing phase facilitates rewarding citizens for their contribution by providing them with co-authorship (Rotman et al., 2012; Franzoni & Sauermann, 2014; Crowston, Mitchell & Osterlund, 2018). Involving them in the dissemination phase of research could stimulate and inspire new science communication concepts, increase knowledge sharing across diverse groups of people, and increase collective capital (Bonn et al., 2016; Chiu et al., 2006; Chang & Chuang, 2011). It would be interesting to gain a better understanding of the potential benefits of co-created citizen science projects. Unfortunately, insufficient knowledge exists to fully shed light on this question and additional research is required (Robinson et al., 2018, in Hecker & Haklay, 2018).

To conclude, all forms of citizen science promise several benefits. Higher forms of citizen science promise added benefits, including access to creative, novel ideas, or better learning of citizens.

3.6 Platform-based organizations

To set the stage for the future analysis, this section provides a background and terms of reference from the existing platform literature.

This thesis frames platforms from an economic and organizational perspective which looks at platforms through a business model lens (e.g. Eisenmann, 2008; Furr, 2016; Boudreau & Lakhani, 2009). From this perspective, platforms refer to a "distinct mode of organizing production and exchange" (Boudreau, 2017, pg. 233). Platform-based organizations (in short, platforms) enable value-creating interactions between different actors (Rochet and Tirole, 2003; Roson, 2005; Parker, van Alstyne & Choudray, 2016; Kohler & Chesbrough, 2019). As orchestrators (Iansiti & Levien, 2004), platforms provide an open, participative infrastructure in which value is created and exchanged and they lay out a framework that governs the interactions and exchange between the actors (Parker, van Alstyne & Choudray, 2016). Typically, technology is leveraged to enable the activities (Kohler, 2015).

Similar to Parker, van Alstyne & Choudray (2016), Kohler & Chesbrough (2019) determine four building blocks that make up a successful platforms' design: actors, value units, interactions, and the business model. Essentially, there are three main *actors* in platform-based interactions. The first is of course the *platform organization* that makes up the platform. The second and third are the *producers or creators* who create value and contribute it so that the *consumers* can consume value. (Parker, van Alstyne & Choudray, 2016; Kohler & Chesbrough, 2019). In some instances, in different interactions, producers are also consumers (Kohler, 2015). *Value units* describe the outcome of the value creation process by the producer (Parker, van Alstyne & Choudray, 2016; Kohler & Chesbrough, 2019). The *interactions* are the activities that take place on the platform that include value creation, curation, and capture (Choudray, 2015). The core interaction shapes which type of *business model* is best suited to create a sustainable platform (Parker, van Alstyne & Choudray, 2016; Kohler & Chesbrough, 2019). Boudreau and Lakhani (2009) propose three types of platform business models that capitalize on the participation of external contributors (i.e. crowdsourcing-based business models). In each model, the platform takes on a different position in the network of actors, changing the setup of who "sells" to whom (Boudreau & Lakhani, 2009; Kohler, 2015).

- In the integrator platform model, the platform collects contributions from creators and distributes the end-product to consumers. The key activity of the platform is to integrate the creators' contributions. As an intermediary placed between the two parties who do not interact with each other directly, the platforms exerts a high degree of control. (Boudreau & Lakhani, 2009; Kohler, 2015).

- In the product platform model, creators build on top of a technology or product and sell the resulting products to consumers. The key activity of the platform is to support development. The platform exerts control over technical design of the core technology but not over the interactions between creators and consumers. Successful product platforms create ecosystems, or platforms of innovation, that benefit from any value-creation on the platform. (Boudreau & Lakhani, 2009; Kohler, 2015).

- On two- or multi-sided platforms, creators and consumers interact directly with each other, while also being affiliated with the platform. The key activity of the platform is to connect creators and customers. Platforms exert some degree of control by setting up rules or regulations as a condition to engage via the platform. (Boudreau & Lakhani, 2009; Kohler, 2015). Successful platforms benefit from network effects with increasing returns (Franzoni & Sauermann, 2014). This means that because actors are attracted to each other, the value of the platform increases with each additional user on the platform (e.g. Eisenmann, Parker & van Alstyne, 2006; Eisenmann, 2008).

One should note that the "sale" in the transactions above is typically paid for by some form of currency. However, this currency need not to take a monetary form. It may also take intangible forms such as attention, fame, influence, or reputation (Parker, von Alstyne & Choudray, 2016).

In this thesis, the above framework is applied to the context of citizen science. Citizens and researchers make up the creators and consumers of value. Of course, a broad variety of transactions or interactions exists. Thus, a variety of business models are present.

3.7 Platforms in citizen science

In this section, an overview of platforms relevant to the field of citizen science is given. Then, platforms within the scope of analysis this thesis are elaborated on. Platforms not within the scope of analysis are touched upon to explain why they are excluded.

To mention the technological design perspective on platforms, the role of traditional and innovative technologies in citizen science has been frequently investigated (e.g. Bonn et al., 2018; Brenton, 2018; Lichten et al., 2018). Technology is often seen as being an essential component to citizen science, as it enables all forms of citizen science engagement ranging from contributory to co-created citizen engagement (Bonn et al., 2018). Scholars differentiate technology or IT infrastructures according to their function and usage in citizen science projects (Bonn et al., 2018; Mazudmar et al., 2018; Brenton, 2018; Newman et al., 2012). This perspective is not applied in this thesis.

With regards to platform-based organizations, the literature occasionally provides an overview of existing online platforms and tools used in citizen science which are structured based on their purpose and functionality (Lichten et al., 2018). Building upon the understanding of the platforms' role in citizen science literature and their application in the practical field, this thesis distinguishes between six types of platform based organizations (from now on referred to as platforms) in citizen science: 1) Project hosting platforms, 2) Project listing platforms 3) Community engagement platforms, 4) Labor market platforms, 5) Crowdsourcing (contest) platforms, 6) Product or service platforms.

Project hosting platforms enable researchers to build and host their citizen science projects on an existing platform. Researchers as project organizers and citizens as interested contributors directly interact with each other. (Lichten et al., 2018 Thus, project hosting platforms are classified as two- or multi-sided platforms.

Project listing platforms such as Scistarter provide a listed overview on active or completed citizen science projects. Among these, there are national and global platforms (Franzoni & Sauermann, 2014; Lichten et al., 2014). National platforms, e.g. 'Bürger schaffen Wissen' or 'Österreich forscht', list national citizen science projects (Richter et al., 2018). Sometimes such platforms are sponsored by citizen science associations (e.g. the German capacity-building program 'GEWISS'). While this thesis generally excludes offline parties from the analysis, it includes platforms created, sponsored or managed by such parties, specifically project listing platforms. Because project listing platforms build a network of project organizers and seekers, they can be classified as two- or multi-sided platforms.

Community engagement platforms facilitate the direct collaboration between researchers and the crowd, and between single crowd members (Mazudmar et al., 2018; Bonn et al., 2018). Hence, community engagement platforms are categorized as two- or multi-sided platforms.

Labor market platforms such as Upwork or Amazon MTurk enable researchers to outsource well-defined research tasks to a large crowd or individual freelancers (Lichten et al., 2018; Franzoni & Sauermann, 2014). Since the researcher as consumer of the performance and the citizen as creator of the compensated output directly interact on labor market platforms, those are also categorized as two- or multi-sided platforms.

In contrast, crowdsourcing (contest) platforms make use of the integrator model. Contest platforms enable researchers to outsource a clearly defined research task or problem to a crowd of problem solvers

(Lichten et al., 2018). For example, InnoCentive encourages citizens to solve scientific problems in prize-based competitions and sells this "product" to its clients (Boudreau & Lakhani, 2009).

Product or service platforms offer researchers an existing technological infrastructure which they can build upon and customize for their project (e.g. Hummer & Niedermeyer, 2018). They can either build upon open source models such as GitHub or commercial models such as Spotteron. Spotteron functions as creator of a scalable technology for citizen science projects and simultaneously consumer of the product development contributions (in the form of ideas for further technological development) from researchers and citizens that expand and improve the functionality of the existing technology (Hummer & Niedermeyer, 2018). Therefore, product or service platforms are categorized as product platforms according to Boudreau and Lakhani (2009)'s classification of platform business models.

In comparison, bespoke platforms are tailored to the specific citizen science project (Brenton et al., 2018), and created without the use of a platform intermediary. Bespoke platforms in this thesis are used as a contrasting group to online platform intermediaries to shed light on limitations of existing platforms (cf. chapter 4, methodology)

Beyond the outlined platform types, the literature also identifies other platforms which this thesis excludes from the analysis. These include crowdfunding platforms (Wyler & Haklay, 2018), educational platforms (Brenton et al., 2018) and platforms serving a distinct purpose, or which are dedicated to certain research activities (explained below) (Strang & Simmons, 2018; Lichten et al., 2018; (Brenton et al., 2018).

Crowdfunding platforms enable researchers to fund a research project by raising small amounts of money from a large crowd (Sauermann, Franzoni, & Shafi, 2019). Crowdfunding presents an alternative and/or complementary source of funding to the current grant and science funding mechanisms (Sauermann et al., 2019). Crowdfunding platforms are excluded from further analysis in this thesis because citizens contribute financial resources to make possible or support a project. However, citizens do not contribute to the completion of scientific tasks by using their cognitive abilities and/or knowledge assets, nor directly impact the research outcome. They therefore cannot facilitate co-created citizen science projects.

Educational platforms or tools provide one-way thematic information which can be accessed by interested parties (Brenton et al., 2018). This thesis also excludes educational platforms since they supply information directly to their consumers, but they do not allow different actors to interact with each other (Brenton et al., 2018).

Distinct purpose platforms or platforms dedicated to certain research activities are those that enable that citizens fulfill only a certain type of task (Strang & Simmons, 2018; Lichten et al., 2018; Brenton, 2018). Examples are the systematic reviewing of literature (Strang & Simmons, 2018; Lichten et al., 2018) or the transcription of audio or text (Brenton et al., 2018). These are excluded from further analysis because they limit the type of involvement of citizens (i.e. few tasks), and are also commonly driven by achieving efficiency gains, which makes it unlikely that they would be used for co-creation purposes (Strang & Simmons, 2018; Lichten et al., 2018).

To conclude, this thesis focuses its analysis on six types of platforms, while excluding other platform types for the above reasons.

4. Literature review: Barriers and platform-based solutions to transitioning to co-created citizen science

This section aims at presenting literature on barriers and solutions to transitioning towards co-creation in citizen science projects and to conducting co-created citizen science. Unfortunately, there is little knowledge on the barriers to co-creation in the current citizen science literature (Ballard et al., 2018). For this reason, the following section presents the limited knowledge available on barriers to co-creation, while also presenting barriers that researchers experience in projects with lower citizen engagement (Bonney et al., 2009). As citizens in co-created projects receive more tasks and decision rights than in classic citizen science projects, the authors expect that many barriers will also be present in co-created projects. They also expect that many will be even more pronounced in co-created projects. The barriers and solutions are structured according to four levels, i.e. 1) the individual (researcher, and citizen) 2) the project 3) the organizational, 4) the ecosystem level. Barriers are followed by their respective solutions below.

4.1 Individual level (researcher) barriers

In this section, individual level barriers are presented. Individual level barriers originate from the individual person, i.e. the smallest unit of analysis. In citizen science, individual person barriers of a researcher or a citizen are analyzed, and may relate to, for example, certain beliefs or personal values of these individuals. Below, first, barriers that concern the individual researcher are presented. hen followed by barriers which originate from the individual citizen.

Barriers of the Individual researcher include that some researchers lack certain skills (e.g. Buytaert et al., 2014; Haklay, 2015; Rotman et al., 2012) or resources. It also includes characteristics of researchers, and perceptions, attitudes, beliefs and values that cause resistance to engage in co-created citizen science (e.g. Powell & Colin, 2008; Thompson et al., 2009).

Insufficient knowledge and skills: Establishing a citizen science project requires certain skills that scientists do not naturally possess (e.g. Berditchevskaia, Regalado, & Duin, 2017; Buytaert et al., 2014; Powell & Colin, 2008). For instance, “a high level of leadership and interpersonal skills” is needed because researchers need to manage human relations and behavior within a group of people and communicate with non-scientists (Buytaert et al., 2014). Especially communication skills are lacking (e.g. Berditchevskaia et al., 2017; Thompson et al., 2009; Haklay, 2015). Some researchers find it challenging to transform scientific language into lay terms (Thompson et al., 2009a), and consequently, citizens may struggle to understand and may be discouraged from becoming engaged in the project (Haklay, 2015). This can have lasting consequences on a project. Another pitfall is the use of a foreign language as means of communication. Many researchers prefer using the English language for communication, as it is commonly used in the research context and required to publish articles in top journals. This risks excluding citizens whose mother tongue is not English. This can prevent researchers from benefiting from a broad knowledge base. Especially for co-created citizen science projects, a clear and inclusive communication style, as well as constant communication strategy is important. Powell & Colin (2009)(M C Powell & Colin, 2009) found that to engage citizens in a participatory and democratic manner, researchers must communicate the project goal and expectations comprehensively, using a clear and transparent wording towards all project participants. An inclusive communication style should address all participants and each participant group equally. This especially concerns underrepresented citizen groups (e.g. Hobbs & White, 2012; Rutten, Minkman, & van der Sanden, 2017; Riesch & Potter, 2014). Some researchers may unintentionally limit their outreach to highly educated and high-income people and exclude members of socio-economically deprived communities. For example, a study showed that promotions for participation in biological research projects addressed the opportunity to learn more about nature in citizens' local surroundings. Many deprived communities however live in areas without access to nature (Rutten et al., 2017). Researchers must also establish continuous communication mechanisms, including social media posts, blogs and newsletter articles, to keep participants engaged in the long-term (Dickinson et al., 2012). To conclude, researchers without communication skills will find it especially difficult to conduct co-created citizen science.

Insufficient resources: A lack of resources is also found to be a common barrier for researchers (e.g. Riesch & Potter, 2014; McKinley et al., 2017). Citizen science projects require a significant amount of resources, including time and money, personnel and tools (McKinley et al., 2017) which are however not always available. Time constraints are a common barrier. Researchers may underestimate the amount of time needed to successfully run a citizen science project. A study by Riesch and Potter (2014) showed that researchers did not realize how time-intensive it was to reach out to and stay in touch with citizens. They also overestimated how fast citizens could complete work, not taking into account that some participants may not participate regularly. The false estimates caused delays and additional effort than initially planned (Riesch & Potter, 2014). Researchers who have experienced such problems in contributory projects may decide against engaging in future co-created citizen science. As co-creation requires an even higher level of time commitment (Dick, 2017), researchers may be discouraged to conduct co-created projects. Another resource barrier is related to money (Franzoni &

Sauermann, 2014). Budgetary restrictions result from researcher's difficulties in receiving sufficient funding. Especially co-created citizen science projects are often insufficiently funded (e.g. Hecker et al., 2018; Powell & Colin, 2008). This problem is discussed in greater detail in a following section on ecosystem level barriers. In summary, a lack of resources, specifically time and money, may present barriers to transitioning to co-created citizen science projects.

Characteristics: In addition, certain characteristics of researchers could provide a barrier to transitioning to co-created citizen science. The seniority level (e.g. full professors have high seniority and PhD students have low seniority) is such a characteristic. Dick (2017) suggests that higher seniority level researchers are often less likely to conduct citizen science projects and particularly deeper forms of citizen science such as co-created citizen science. Dick (2017) argues firstly, that senior academic researchers may be more conservative due to years of formal training and focus on achieving performance influenced by the academic promotion system that follows traditional scientific standards. Secondly, senior academic researchers often perceive that their main obligation lies in generating qualitative scientific outcomes. Communicating scientific results to the public or engaging citizens often becomes peripheral. Thirdly, Dick (2017) highlights that senior researchers have little exposure outside their academic field. This focus makes it difficult for them to relate to the public and work outside of academia.

Perceptions, attitudes, beliefs, values: Further barriers relate to the perceptions, attitudes, beliefs and values of researchers cause resistance of scientists to engage in co-created citizen science (e.g. Hecker et al., 2018; Mckinley, Briggs, & Bartuska, 2012; Powell & Colin, 2008). Some researchers' view of academic principles and their philosophy contradicts with the approach of involving citizens beyond data collection. They believe that research should be led by scientists (McKinley et al., 2012). This "ivory tower mentality" creates a barrier to transitioning to co-creation (Hecker, Bonney et al., 2018:4). Similarly, some researchers perceive citizen involvement as a threat (e.g. Powell & Colin, 2008; Thompson et al., 2009). A qualitative study on the attitudes of UK health researchers towards engaging non-scientists in revealed a fear that scientific research would become de-professionalized and that citizen involvement would erode the skills and knowledge of academics. They did not accept that knowledge acquired through lived experience as a legitimate scientific knowledge (Thompson et al., 2009a). Other researchers don't co-create because they are reluctant to share the control over certain research phases, e.g. the experimental study design or the collection and interpretation of data (McKinley et al., 2012), or share control over a study in general (Thompson et al., 2009). Others reject the idea that a volunteer's position is equal to the researcher's (McKinley et al., 2012). Researcher's hesitancy to co-create can also result from a fear of uncertainty and reluctance to change. Citizen involvement in research challenges the traditional knowledge production and acquisition in science, exposing researchers to new ways of working. Researchers sometimes are afraid to engage in new ways of working and to expose their working practice to the outside world (Thompson et al., 2009). This fear specifically applies to scientists who conduct basic research in which citizen science approaches are less common compared to applied or social sciences (McKinley et al., 2012). Researchers can also experience insecurities. For example, some researchers are uncomfortable to co-define a research question together with citizens after the project start as this is not the typical approach (Thompson et al., 2009). A lack of knowledge, creativity or confidence in designing a project, and potentially a co-created project, can also cause hesitancy (Hecker et al., 2018; Shanley & López, 2009). Further, actively involved citizens might question the direction of the study or confront researchers with uncomfortable questions that are outside of the researcher's field of expertise (Powell & Colin, 2008).

Another reason for a reluctance to co-create relates to researchers distrusting citizens in delivering qualitative and valid contributions (e.g. Riesch & Potter, 2014; Theobald et al., 2015). Academic articles frequently show that scientists who involve citizens in data collection are afraid to receive low quality results (Riesch & Potter, 2014; Snow, O'Connor, Jurafsky, & Ng, 2008; Rotman et al., 2012; Theobald et al., 2015). Thus, researchers engaging in contributory citizen science projects may be demotivated to conduct co-created citizen science projects. If researchers are skeptical of citizens conducting simple tasks such as data collection, they are unlikely to expand the involvement into more complex research phases. One should note however that researchers' familiarity with citizen science reduces the skepticism towards citizen contributions (Theobald et al., 2015). In fields in which citizen science is more common, e.g. in the field of ontology, researchers are more likely to disseminate citizen science data than in fields in which citizen science is less represented. This indicates that the research area influences the distrust barrier.

Similarly, to counteract quality concerns, citizen science project leaders must consider and control for limitations and biases in their studies, as in any other research approach (Ballard, Phillips, & Robinson, 2018, p. 36). However, project leaders don't always have sufficient quality assurance (QA) mechanisms to control, measure, and report data quality (Ballard, Phillips, & Robinson, 2018, p. 36). For example, biology researchers with insufficient QA mechanisms had to explain variances in findings which could not be attributed to biological occurrences; they were related to varying sampling effort (Dickinson et al., 2010a). Low data quality in citizen science research resulted from non-standardized or poorly designed methods for data collection (Hunter, Alabri, & van Ingen, 2013), e.g. inconsistent monitoring protocols (Milne et al., 2006), the lack of an appropriate experimental design and adequate sampling sizes (Conrad & Hilchey, 2011), a lack of pilot studies (Rutten et al., 2017) and insufficient quality assurance and control (Rutten et al., 2017; Rotman et al., 2012). Thus, researchers without appropriate QA procedures and mechanisms are exposed to low quality of research. However, researchers must strike a balance between QA and participant motivation, which is not an issue in non-citizen research projects (e.g. Rutten et al., 2017). For example, high sampling frequency may result in more consistent data collected by citizens but may be perceived as burdensome by citizens (Theobald et al., 2015). Thus, citizen science researchers must set up an appropriate study design, account for biases and limitations while also accounting for the needs of citizens, which is challenging as complexity increases.

4.2 Solutions to individual level (researcher) barriers

This section presents solutions to individual (researcher) level barriers, including a lack of communication and leadership skills, as well as for solving methodological concerns. However, the literature does not provide solutions for the other barriers, e.g. characteristics of researchers or certain perceptions such as having an ivory tower mentality. Therefore, this section does not present such solutions.

Solutions to insufficient knowledge and skills: An individual researcher level barrier is that some researchers lack sufficient skills (Buytaert et al., 2014; Haklay, 2015; Rotman et al., 2012) such as leadership and communication skills (e.g. Berditchevskaia, Regalado, & Duin, 2017; Thompson et al., 2009). The literature indicates that platforms may offer solutions to researchers who lack leadership skills. While uncommon, Franzoni & Sauermann (2014) suggest that leadership functions could be incorporated into a technical infrastructure of a platform. For example, Foldit, a bespoke protein folding game and puzzle leads citizens by limiting the operations allowed through the system. Franzoni & Sauermann (2014) also suggest that non-researchers such as platform stakeholders or experienced citizen-science project managers sometimes hold leadership positions. Designers of collaboration tools or experienced hosting platform employees could also be fit into leadership roles (Franzoni & Sauermann, 2014b). New leadership models should be used with caution in co-creation projects. Demands on and for (continuous) leadership are high in these projects (Dickinson et al., 2012; Franzoni & Sauermann, 2014; Crowston, Mitchell, & Østerlund, 2019) and new leadership models may therefore not suffice. The example of the Galaxy Zoo Quench project underpins this. The project aimed to research, write, and publish an academic paper with citizens but failed, among other reasons, because a lead scientist became unavailable during the analysis phase. The project was never completed as a suitable replacement was not available to provide specific guidance on the analyses (Crowston et al., 2019).

Another individual researcher level barrier is that some researchers have insufficient communication skills. Platforms can help researchers translate scientific language into lay terms (Thompson et al., 2009a) by allowing researchers to visualize and communicate scientific content in a clear and understandable way. Infographics, i.e. imagery, charts, and minimal text embedded in applications and websites, can give citizens a quick and easy-to-understand overview of scientific content (Buytaert et al., 2014; Spiegelhalter et al., 2011). Advanced platforms tailor the user interface to the user. For example, a gaming engine for 3D visualization of geospatial data adjusts the user interface towards experts and non-experts (Snow et al., 2008). Further, certain platform mechanisms help researchers to establish more inclusive conversations with citizens (Collins & Evans, 2002). Asynchronous discussion forums of community engagement platforms can, for example, encourage an interactive debate between researchers and citizens, instead of top-down communication from researchers to citizens (Raddick et al., 2010; Roy, Pocock, Preston, Roy & Savage, 2012).

Solutions to perceptions, attitudes, beliefs: An individual (Martin & Greig, 2019) researcher level barrier is identified as the perception, attitudes, beliefs, or values that cause researchers to be reluctant to engage in co-created citizen science (e.g. Hecker et al., 2018; McKinley et al., 2012). The literature shows that platforms can counteract researchers' distrust in citizen contributions by increasing and evaluating the quality of contributions (e.g. Riesch & Potter, 2014; Theobald et al., 2015). They address methodological concerns by incorporating quality assurance mechanisms such as training, qualification tests, digital filters into the platform's infrastructure (e.g. Forrester et al., 2017; Dickinson et al., 2012; Preece, 2016; Strang & Simmons, 2018). The mechanisms used are presented in the following section on individual citizen solutions.

To conclude, the literature shows that platforms only partially solve barriers related to the individual researcher. The results are summarized in Table 2 below.

Level	**Barriers in (co-created) citizen science**	**Platform-based solutions**
Individual (researcher)	*Insufficient knowledge and skills*	
	Leadership and interpersonal skills	– Technical infrastructure incorporates leadership functions – Platform stakeholders take on leadership positions
	Communication skills	– Visualization and clear communication of scientific content – Adjusted user interfaces towards experts and non-experts – Asynchronous discussion forums
	Characteristics	
	High seniority	No solution
	Insufficient resources	
	Time, i.e. limited capacity and mismatches in schedules	No solution
	Perceptions, attitudes, beliefs, values, etc.	
	Ivory tower mentality	No solution
	Reluctance to share control and give up power	No solution
	Fear of uncertainty & reluctance to change	No solution

	Experiencing insecurities (e.g. lack of confidence in designing project)	No solution
	Distrust of citizens contributions (quality concerns & lack of quality assurance)	– Quality assurance mechanisms

Table 2: Barriers and solutions to individual (researcher) barriers

4.3 Individual level (citizen) barriers

In addition to barriers related to factors attributed to researchers, there are barriers that can be attributed to citizens. These include insufficient knowledge and resources, certain characteristics or demographics of citizens, their perceptions, attitudes, beliefs, and values, and a lack of motivation. They are elaborated below.

Insufficient knowledge and resources: Haklay (2018) suggests that time and knowledge constraints limit the feasibility of co-created citizen science. The paper compares the benefits and challenges of citizen science project participation in terms of the level of knowledge acquired through (higher level) education and time and effort citizens invest in the project activities. Haklay (2018) suggests that opportunities for deeper engagement, including analyses and paper writing, arise from involving citizens with high levels of knowledge who have time to contribute their expertise. In contrast, lighter forms of citizen science are more suited for citizens with a high level of knowledge but limited time to invest (Haklay, 2018). When citizens have a low level of knowledge, contributory projects are best suited (Haklay, 2018). Much support and facilitation is necessary to increase the mutual benefits of the engagement (Haklay, 2018). Whereas appropriate training would increase the value of citizen's continuous contributions (Edwards, 2014b), citizens might not have time to participate in extensive training (McKinley et al., 2017). Thus, time and knowledge constraints present barriers to transitioning to co-created citizen science. Several studies analyzing participation levels of citizens support Haklay, (2018)'s claim that time constraints of citizens present a barrier (Rutten et al., 2017). For example, in a case study on the bird-feeding program Feederwatch, Martin & Greig (2019) explored the drivers and barriers of young adult participation. The leading barrier was a lack of time. Similarly, Merenlender, Crall, Drill, Prysby and Ballard (2016) reported that younger adults could not commit to voluntary activities because they need time for career advancement opportunities and family duties. Similarly, researchers confirm that citizens sometimes lack sufficient skills. Earlier, Haklay (2015) already showed that citizen participation is limited by citizen's technical and domain knowledge and skills. Strang and Simmons (2018) argue that citizens typically have variable knowledge and competence, often lacking formal training for skills such as systematic reviewing.

Characteristics and demographics: Another barrier is related to citizens' demographics. A potential advantage of co-creation results from the combination of diverse participant-knowledge. However, it is not always possible for researchers to attract a broad and diverse participant base because certain demographics cannot easily participate. A lack of skills, financial means, technology and equipment hinder meaningful participation especially in rural areas of developing countries (e.g. Braschler, 2009; Rotman et al., 2012; Rutten et al., 2017; Hobbs & White, 2012). Also, poor health conditions or disabilities hinders research project participation (Pope, 2005). The inability to obtain a broad and diverse participant base could make a co-creation approach less attractive to researchers.

In some cases, demographics and skills are related. Demographics and geography affect IT skills and tech savviness (e.g.(Newman et al., 2012a)). Many contributory citizen science projects contain an online element (Pocock et al., 2017) and require citizens to have some proficiency in using digital technologies. However, some interested participants may be hindered due to a lack of sufficient IT or technical skills ("Citizen Science and Policy : A European Perspective by Muki Haklay," n.d.). Especially older generations prefer to work with offline instruments such as paper logbooks (Williamson, K., Kennan, M. A., Johanson, G., & Weckert, 2016) (Williams, Chapman, et al., 2018). The literature provides limited insights on the importance of technical skills in co-created citizen science projects, but some hypotheses can be made. On the one hand, co-created projects may benefit from offline rather than online communication, e.g. face to face meetings, as this enables participants to interact personally and build trust. In local projects, where face-to-face meetings are feasible, a lack of technical skills would therefore not be problematic. On the other hand, large-scale or global projects with dispersed participants need to rely on technology to enable a higher level of participant interaction, which increases demands for technical skills. Hence, depending on the project's set-up, a lack of technical skills may or may not present a barrier to transition to co-created projects.

Perceptions, attitudes, beliefs, values: Perceptions and attitudes of citizens can present barriers to transitioning to co-created citizen science projects. Studies investigating citizen's drivers and barriers report that some citizens are not confident that their knowledge assets suffice to take part in a research project (e.g. McKinley et al., 2017; Merenlender, Crall, Drill, Prysby, & Ballard, 2016). For example, some citizens are not confident to identify species correctly in conservation studies. The lack of confidence causes citizens to withdraw from participation, even though they may actually possess sufficient knowledge to participate (Predavec et al., 2016). This could potentially prevent researchers from recruiting enough participants for co-created citizen science projects. The lack of confidence in their knowledge assets negatively impacts the willingness to take on greater responsibilities, more tasks and share decisions.

Lack of (sustained) motivation: Scholars have identified that a lack of interest or motivation of citizens for (sustained) participation forms a major barrier to citizen science projects (e.g. Franzoni & Sauermann, 2014; Rutten et al., 2017). Ensuring that citizens are motivated and dedicated to participating in co-created projects could be even harder.

Firstly, some citizens may not be willing to make a large investment in effort and time required by deeper levels of engagement. Literature on citizen science shows that most volunteers make only small and infrequent contributions and only a small group of volunteers makes the large contributions (Franzoni & Sauermann, 2014b). It is likely that only the latter group would be interested in participating in co-created citizen science projects. Thus, citizen science project managers should not presume a certain level of interest but rather give citizens the freedom to choose their own level of participation (Susanne Hecker, Bonney, et al., 2018).

Secondly, researchers conducting co-created studies in certain research fields may find it difficult to attract participants. Citizens may also find fulfilling certain tasks uninteresting. While citizens are oftentimes highly motivated to contribute if the research fits to their interests and needs, they can be demotivated if it does not. For example, citizens were found to be less attracted towards narrow or non-socially relevant research fields (Frigerio et al., 2018; Sauermann & Franzoni, 2015) or certain study objects such as rats or insects (McKinley et al., 2017b) or certain activities such as nature-related monitoring tasks (Deutsch & Ruiz-Córdova, 2015a). The latter is especially true for young adults who are increasingly detached from nature.

Ensuring sustained volunteer participation presents another challenge. Co-created citizen science projects may be affected by discontinued citizens' contributions. The citizens' interest and contributions diminish throughout the study period (Wiggins & Crowston, 2011b) and citizens may quit shortly after joining (Franzoni & Sauermann, 2014b). Volunteers may drop out if they perceive that their contributions are not used (Conrad & Hilchey, 2011; Rotman et al., 2012a; Rutten et al., 2017).

To foster and ensure continued volunteer participation in co-created citizen science projects, researchers must address *the right* motivational drivers of citizens (Susanne Hecker, Bonney, et al., 2018; Rotman et al., 2012a). This is not easy because participation in co-created projects may be driven by different motivational factors than in other (e.g. contributory) projects (Reed, Raddick, Lardner, & Carney, 2013). A study investigating different levels of citizen involvement showed that intrinsic motivational drivers were strongest in contributory citizen science projects, whereas extrinsic motivation was more in co-created projects (Phillips et al., 2019). Volunteers contributed to co-created projects because of environmental concerns, worries, and fears, whereas fun and joy motivated volunteers to participate in contributory projects. The study highlights the complexity of motivation in the field of citizen science.

To conclude, barriers to transitioning to co-created citizen science projects exist for citizens and include factors such as a lack of skills, resources or negative attitudes and perceptions.

4.4 Solutions for individual citizens

This section describes how platforms address barriers associated with citizens. Training, education, and quality assurance mechanisms help solve barriers related to insufficient knowledge and skills and citizens lack of confidence. Further, platforms offer solutions to increase citizen motivation in citizen science projects. However, the literature does not identify solutions to other barriers such as insufficient resources, characteristics, and demographics. Therefore, this section does not present such solutions.

Solutions to insufficient knowledge and skills: An individual-citizens level barrier is that some citizens lack sufficient skills. The literature shows that platforms can reduce barriers related to a (perceived) lack of skills of citizens (e.g. Haklay, 2018; McKinley et al., 2017; (Merenlender et al., 2016a). One solution is training. Training allows interested individuals to build a sufficient knowledge base and increases the quality of contributions of citizens. Some platforms train citizens or guide them through the process. The eMammal platform, an independent platform for gathering, storing, and sharing survey data on mammals, for example combined an initial in-person training with follow-up online training that included members writing articles for the eMammal blog. As a result, volunteers improved their species-identification skills (Forrester et al., 2017). Other platforms educate citizens online using instructions, videos, and/or FAQs (See et al., 2016; Wang, Kaplan, Newman, & Scarpino, 2015). Some projects also use online services such as Google spreadsheets to assemble observations and provide immediate feedback (e.g. d'Alessio & Lundquist, 2013). While these examples show how platforms support learning through training, it should be noted that the spectrum of educational training in citizen science is large, comprised of formal and informal training, conducted offline and online. Formal training can include mechanisms such as onsite workshops, multi-day training programs or online training modules (Gallo & Waitt, 2011; van der Velde et al., 2017). Informal training can include mechanisms such as educational material, online knowledge libraries and feedback loops on participants' contributions (Forrester et al., 2017). Any of the educational learning mechanisms can result in skill improvements that create higher quality contributions (Gallo & Waitt, 2011; van der Velde et al., 2017; Forrester et al., 2017).

Other solutions to help researchers cope with a lack of skills of citizens. Some platforms try to increase the quality of contributions by limiting the group of contributors to the project ex-ante. Labor market platforms often allow researchers to specify criteria that contributors must meet to work on a task (Harmon & Silberman, 2018). An example is Amazon MTurk that allows researchers to search for individuals with certain qualifications (Harmon & Silberman, 2018). Some platforms eliminate potential contributors who fail qualifications tests that evaluate their task-related ability (e.g. (Dickinson et al., 2012; Strang & Simmons, 2018). Strang and Simmons (2018) analyzed case studies where non-scientists were involved in conducting a systematic literature review via different online platforms. The authors show how qualification tests combined with other quality control mechanisms produced a relatively high accuracy. Another common quality control mechanism in labor market platforms is to allow researchers to block individuals who have previously produced unsatisfactory quality (Harmon & Silberman, 2018). Dickinson et al. (2010) suggest that error and bias can be eliminated by excluding individuals such as first-year participants or people who submit erratically or erroneous reports.

Other platforms help evaluate and validate contributions when the project is running, filtering out low-quality or lower-quality contributions in the process. Peer evaluation helps the quality of the contributions (Kittur, Smus, Khamkar, & Kraut, 2011). Simple and effective methods are voting (i.e. the crowd chooses one output from multiple outputs) or verification (i.e. one volunteer verifies the results of another) (Kittur et al., 2011). An even more effective, more complex method is to have contributors combine the best parts of various contributors' outputs into a single best output (Kittur et al., 2011). Other state-of-the art methods combine digital filtering systems and humans' experts to check for accuracy. Examples are eBird's and FeederWatch's method of validating data quality. Here, the digital filtering system flags questionable data first, and then the flagged data is checked for accuracy by experts (Preece, 2016; Dickinson et al., 2010). The combined approach has allowed for a rapid data review and has produced quality data that is used by scientists and citizens worldwide (Preece, 2016). Other best practice examples are the Open Dinosaur and Galaxy Zoo projects in which citizen contributions are verified through a process in which multiple citizens conduct the same task and all results are compared through the system, disregarding outliers (Franzoni & Sauermann, 2014; Lintott et al., 2014).

Solutions to a lack of motivation: Another individual-citizens level barrier is that some citizens lack sufficient motivation. One challenge for project leaders is to foster and ensure continued participation by addressing the right motivational drivers of citizens (Susanne Hecker, Bonney, et al., 2018; Rotman et al., 2012a). While platforms don't necessarily help to identify the right motivational driver, they help researchers to motivate the crowd by touching upon various intrinsic and extrinsic motivation of citizens (e.g. Wald, Longo, & Dobell, 2016).

Important internal motives are personal interest and learning (Domroese & Johnson, 2017; Franzoni & Sauermann, 2014a; Predavec et al., 2016) and social benefits (Hars & Ou, 2002). Platforms offer support to keep participants who are interested in a certain topic engaged. Franzoni & Sauermann (2014) highlight that hosting platforms such as Zooniverse provide scientific background information and regularly share topic-related information. They also allow users to store interesting objects or pictures in their user profile. Platforms also offer learning opportunities for the crowd. One learning method is to provide feedback by providing explanations in addition to information on the correctness of a task. Platform technology can be used to create feedback automatically (van der Wal, Sharma, Mellish, Robinson, & Siddharthan, 2016). Emerging technologies such as gamification and VR can also help to improve the learning experience (Preece, 2016). Motivation also arises from social interaction with people who have similar interests (Merenlender et al., 2016a) or from whom one can learn (Aitamurto, Landemore, & Saldivar Galli, 2017), and can be related to feeling part of a community (Budhathoki & Haythornthwaite, 2013). Some platforms also address "social benefits" of citizens (Hars & Ou, 2002). In studies, participants said that social engagement was an important reason for contributing to projects on the hosting platform Zooniverse (Reed et al., 2013) and the wiki OpenStreetMap, a citizen science site for voluntary geographic information (Budhathoki & Haythornthwaite, 2013).

Additionally, some platforms help researchers to motivate the crowd using extrinsic factors. According to Franzoni and Sauermann (2014), projects that want to attract a diverse group of individuals (that includes experts and non-experts) may have to offer more “traditional payoffs” such as the assignment of authorship or cash payments. Monetary rewards and career aspirations can be especially important motivators for expert contributors (Budhathoki & Haythornthwaite, 2013). Some platforms provide financial incentives. The labor market platforms Amazon MTurk and Upwork for example pay freelancers for their work (Kittur et al., 2011; Lichten et al., 2018). However, it is unclear if these mechanisms are sufficient (Franzoni & Sauermann, 2014a). Other platforms address norm-oriented or social motives associated with motivation resulting from the expected reactions of others as well as reputation (Nov, Arazy, & Anderson, 2014). Some hosting and independent platforms measure the level of participation and the contribution quality, thereby enticing participation (Nov et al., 2014). Leaderboards and scoring are inherent features that many platforms, e.g. the independent platform Eyewire, possess (Tinati, Luczak-Roesch, Simperl, & Hall, 2017).

A barrier is that some research fields and tasks are uninteresting to citizens (e.g. Deutsch & Ruiz-Córdova, 2015). As a solution to this problem, some platforms help to identify interested participants and spark a higher level of curiosity for particular fields. By broadcasting scientific problems to a large crowd, hosting platforms increase the chance that someone will find the topic interesting and decide to participate (Franzoni & Sauermann, 2014a).

To conclude, platforms partially address barriers related to the individual citizen by offering education, quality assurance, and mechanisms to increase motivation. The results are summarized in Table 3 below.

Level	Barriers in (co-created) citizen science	Platform-based solutions
Individual (Citizen)	*Insufficient knowledge and skills*	
	Low education level	– Quality assurance mechanisms, i.e.: training and education, ex-ante quality assurance (e.g. limit the group of contributors), process-based quality assurance (e.g. digital filtering systems)
	Insufficient scientific literacy	– See above
	Insufficient domain knowledge	– See above
	Insufficient resources	

	Time	No solution
	Characteristics and demographics	
	Geographic location	No solution
	Health status	
	Age (elderly)	No solution
	Perceptions, attitudes, beliefs, values, etc.	
	Lack of confidence in one’s knowledge assets	– Initial training (before project start)
	Lack of (sustained) motivation	
	Interest spread among different citizen groups (i.e. few very interested participants)	No solution
	Lack of interest in certain research fields	– Identify interested participants through broadcasting
	Diminishing interest over time (e.g. due to lack of appreciation)	No solution
	Addressing the wrong motivational drivers	– Touch upon intrinsic motives (e.g. personal interest, learning, social benefits) – Touch upon extrinsic motives (e.g. provision of payment, reputational benefits through leaderboards, etc.)

Table 3: Platform-based solutions to individual (citizen) barriers

4.5 Project level barriers

This section presents project level barriers. The project level consists of the project itself (e.g. how it is set up) and concerns the citizens science project team and participants that act as a group of individuals aiming to achieve a certain goal. Barriers on this level originate from the research or project itself, an unsuitable setup or structure (e.g. governance structure), coordination problems, and (negative) group level interactions.

Research project characteristics: A barrier originates from the research project or the study itself. The literature finds that not all topics are feasible for citizen science (McKinley et al., 2017; Pocock, Chapman, Sheppard, & Roy, 2014). For example, the investigation of highly complex phenomena or which demand extensive or longitudinal sampling efforts from participants are considered inappropriate (Buytaert et al., 2014b; McKinley et al., 2017a; Theobald et al., 2015). Novel research topics or research that applies new methods (e.g. in the field of political science or biotechnology) tend to be less applicable to citizen science because research procedures and performance metrics cannot be standardized (Vasileiadou, 2015). In addition, scholars have found that certain research disciplines are not well suited for citizen science (e.g. McKinley et al., 2017a; Theobald et al., 2015).For co-created citizen science, the number of suitable research disciplines could be even more limited. For example, in social science, while citizens are often study objects, researchers are not typically involving citizens actively in the research process (Pettibone et al., 2018). The study of social systems and processes face increased methodological and ethical challenges (Pettibone et al., 2016; Purdam, 2014). Ethic boards may not approve a citizen science approach because of risks on multiple levels. Alternatively, researchers inexperienced in citizen science methods (Williams, Chapma, et al., 2018) may be reluctant to engage in co-created citizen science due to their insecurities (Hecker et al., 2018; Shanley & López, 2009).

Project set-up: Co-created projects may be hampered by governance structures that limit personal interaction (Rotman, Hammock, Preece, Hansen, & Boston, 2014). For example, some centralized and strictly hierarchical project governance structures do not allow researchers and citizens to interact on an eye-level. This could hamper the creation of personal relationships and trust. Trust, however, is, to the belief of the authors, particularly important in co-created projects, as researchers and citizens must equally rely on each other.

Project coordination: Another barrier to transitioning to co-creation are coordination problems. The matching of projects and their respective tasks to citizens' interest and skills presents a (simple) coordination problem in all types of citizen science projects, from contributory to co-created (Franzoni & Sauermann, 2014a). However, task design and allocation can be a hurdle. Co-created citizen project leaders must design tasks so that citizens can be involved in as many research tasks as possible, including complex tasks (Crowston, Mitchell, & Østerlund, 2018), while ensuring that citizens are capable and interested in completing those tasks (Dickinson et al., 2010; Parsons et al., 2011). Scholars agree that simple, recurring or consecutive tasks may become unattractive for citizens who get frustrated if not given greater task freedom or responsibilities (N. R. Prestopnik & Crowston, 2012; Sprinks, Wardlaw, Houghton, Bamford, & Morley, 2017). However, scholars disagree on about the suitability of complex tasks for citizen science. Some scholars believe that complex methods or taxonomies are not particularly suited for citizens (Dickinson et al., 2010; Preece, 2016), while other scholars believe that complex tasks are particularly interesting as they spark intrinsic motivation from social benefits[1] achieved through participant interaction (Franzoni & Sauermann, 2014a; Reed et al., 2013).

[1] Social benefits result from social engagement or personal interactions with people who have similar interests (Merelender et al., 2016) or from whom one can learn (Aitamurto, Landemore & Saldivar Galli (2016), and can be related to feeling part of a community (Budhathoki & Haythornthwaite, 2013)

Research also suggests that co-created projects face more complicated problems that arise from the complexity of specific research phases (Crowston et al., 2018). For example, coordinating paper writing is expected to be complicated due to dependencies between different parts that prevent independent writing. Thus, co-created citizen science projects have a unique problem to coordinate the work between individual members of the crowd. Rutten et al. (2017) suggest breaking down tasks into smaller sub-tasks and then allocate them to suitable, potentially different individuals. Similarly, Franzoni and Sauermann (2014) suggest modularization into sub-tasks of varying complexity facilitates the ability to find suitable contributors. Overall, co-created projects need to address coordination problems.

Group level interactions: Finally, research teams in co-created citizen science projects face hurdles in group level interactions. Typically, the research team and volunteers collaborate with each other in an interdisciplinary manner and interdisciplinary collaboration is oftentimes challenging (e.g. Hobbs & White, 2012; Lucrezi, Milanese, Palma, & Cerrano, 2018; Thompson et al., 2009). For instance, establishing group alignment is challenging (Powell & Colin, 2009).

To conclude, the literature highlights several possible project level barriers, ranging from research project characteristics, to project set-up, coordination problems, to group level interactions.

4.6 Platform based solutions to project level barriers

This section presents platform-based solutions to project level barriers. While the literature does not provide platform-based solutions to challenges related to finding a suitable research study, governance model, and problems in group level interactions, platform-based solutions to coordination problems exist. These are outlined below.

Solutions to coordination problems: A barrier on the project level are coordination problems. Platforms help reduce coordination costs by providing features for task design, task allocation and structuring of teamwork. While the literature does show how platforms help to design tasks, it shows that platforms can remove motivational barriers resulting from bad task designs. For example, platforms employ "gamification" and "competition" features to make boring tasks more interesting (Preece, 2016). In "Eyewire", where participants deduced the structure of neurons by performing basic region-marking tasks in a 2D visualization, gaming and entertainment were important drivers for participation. Periodic team competitions and challenges and a real-time chat function made the simple task more appealing (Tinati, Luczak-roesch, Kleek, Simperl, & Shadbolt, 2015).

Platforms also offer features for task allocation. They efficiently match projects with citizens (Franzoni & Sauermann, 2014a; Minkman, Rutten, & van der Sanden, 2017; Rotman et al., 2012a). Franzoni and Sauermann (2014) and Rotman et al. (2012) suggest ways in which platforms do this. Firstly, hosting platforms host multiple projects and allow these projects to make use of a common pool of potential contributors. This mechanism has two key advantages. One, citizens using the platform can identify and self-select to projects that match their interests and (perceived) skills. This presents an efficient matching mechanism. Two, especially when projects on the platform are similar, the platform and consequently the projects on the platform will benefit from network effects. The more (similar) projects are launched, the more suitable contributors will be attracted to the platform, and vice versa. This increases the number of projects and citizens efficiently matched (Franzoni & Sauermann, 2014). Secondly, listing platforms list and distribute information on active and completed projects. This mechanism helps citizens to gain an overview of available projects and thereafter choose suitable projects. Here again, the problem of efficiently matching projects and citizens is solved as citizens self-select into projects that match their interest and (perceived) skills (Franzoni & Sauermann, 2014).

Platform features also help structure the work between individual members of the crowd. Features are available to divide tasks and integrate contributions of team members (Franzoni & Sauermann, 2014). Some platforms such as the crowdsourcing (contest) platform Innocentive offer advisory services to help researchers break down the problem or task appropriately so that it can be distributed and solved easily (Innocentive, 2019b). When tasks are highly modularized, the following integration is easy; the platform simply adds together individual contributions to comprise a whole (Jeppesen & Lakhani, 2010). In contrast, some tasks are difficult to modularize and consequently difficult to integrate (Franzoni & Sauermann, 2014). Collaborative problem-solving projects such as Polymath, where a solution is developed interactively through discussion, rely on informal coordination mechanisms which require large time commitments. In Polymath, participants had to take the time to read and process each other’s contributions. While filtering and sorting mechanisms can support the integration process, it is evident that the number of contributions also needs to be limited so that information can be efficiently and effectively processed (Franzoni & Sauermann, 2014).

To conclude, platform-based solution to coordination problems are available. The results are summarized in Table 4 below.

Level	Barriers in (co-created) citizen science	Platform-based solutions
Project and team	*Research project characteristics*	
	Unsuitable research study (i.e. the research question) and discipline	No solution
	Project set-up	
	Governance structure (hierarchical)	No solution
	Project coordination	
	Task design	– Reduce negative effects of bad task design through gamification and competition

	Task allocation	– Matching through self-selection mechanisms (e.g. common pool of contributors, list & distribute projects)
	Structuring teamwork	– Features to divide tasks and integrate contributions
	Group level interactions	
	Challenges in group alignment in interdisciplinary teams	No solution

Table 4: Platform-based solutions to project level barriers

4.7 Organizational barriers

This section presents barriers created by the organization (i.e. the research institution) at which a researcher is employed. Barriers originate from research institutions that do not sufficiently support researchers in co-creation endeavors. These include resource and infrastructure constraints, as well as an unaligned mission or strategy.

Resource and infrastructure constraints: Due to resource constraints, some organizations cannot sufficiently support researchers who would like to pursue co-created citizen science projects. Engaging citizens more deeply in citizen science requires administrative, advertising and technical "coordination and support from multiple divisions across the university" (Dick, 2017: 1853). The institution needs to provide personnel who are willing to dedicate a significant amount of work towards supporting the citizen science study. However, the availability of organizational resources constrains the extent to which an institution can support citizen science activities (Haklay, 2015).

Inadequate organizational facilities, e.g. a sophisticated technological infrastructure, present further constraints. Often, citizen science creates vast amounts of heterogeneous data that needs to be processed and stored (Mazumdar et al., 2018; Newman et al., 2012). Researchers often rely on the institution's technical infrastructures to process and store data. For example, researchers receiving data inputs from citizens via spreadsheets could benefit from an online data repository to store and share data among participant (Haklay, 2015). However, especially smaller or badly funded institutions have limited technical capabilities due to their lack of investments in modern cyber infrastructure (e.g. Cooper et al., 2007; Dickinson et al., 2012; Mazumdar, Wrigley, & Ciravegna, 2017). Thus, the research institution's technical infrastructure and monetary resources sets boundaries for citizen science projects (Haklay, 2015). The authors expect that technological barriers are especially problematic for large-scale co-creation projects or projects with dispersed participants. Such projects require more sophisticated technical solutions to facilitate collaboration and support the interactive sharing of results.

Strategy and mission: In addition, the organization's mission may present a barrier to pursuing co-created citizen science projects. The mission, which is influenced by an organization's' senior leadership, governance structure or organizational policy, determines the degree to which the organization supports citizen science (Dick, 2017; Haklay, 2015), and therefore co-created citizen science. The authors expect that especially changes in leadership and mission can put co-created citizen science projects at risk as funding could be allocated to other organizational endeavors.

To conclude, researchers willing to conduct a co-created citizen science project may be hindered by insufficient support from their research institution.

4.8 Platform based solutions to organizational level barriers

In this section, platform-based solutions to organizational level barriers, including resource and infrastructure constraints, and strategy and mission related barriers are presented.

Solutions to resource and infrastructure constraints: The lack of resources such as staff and money and inadequate (technical) infrastructures provided by research institutions for co-created citizen science projects is an organizational barrier.

Platform can help researchers cope by providing complementary resources that compensate for organizational shortcomings. Platform intermediaries can help researchers implement citizen science projects when researchers have limited access to personnel. For example, projects requiring classification tasks can make use of Zooniverse's online project builder that allows anyone to build their own citizen science project without having to hire developers (Lichten et al., 2018).

Some projects struggle because their organization cannot provide a sufficient technical infrastructure and technical support. Platform intermediaries can be external providers of a technical infrastructure and of modern technologies. Platforms can provide a modern cyber infrastructure needed to store, manage, and process large amounts of heterogeneous data generated by (large-scale) citizen science activities. Zooniverse also supports the processing of large amounts of data; the crowd classifies images, transcribes text, and so on (Lichten et al., 2018). There are also platforms that support the classification of data other than images, e.g. Cochrane Crowd is a platform for systematic reviewing of scientific articles (Lichten et al., 2018). Solutions for management of large data sets are also available. An example are data repositories such as DataOne, a service provider that supports researchers in managing, documenting and sharing data (McKinley et al., 2017). Some platforms take over data management by integrating technologies such as artificial intelligence which can help the researcher classify the scientific content.

Solutions to strategy and mission related barriers: Additionally, platforms may help when an organization's strategy and mission are not aligned with citizen science or co-creation by increasing organizational buy-in. National platforms are successful advocates for citizen science (Hecker et al., 2018). The Austrian national platforms “Österreich forscht” and the “Center of Citizen Science” have established the term “citizen science” at research institutions, in the media and in research policy. One measure to build citizen science capability in the country was to promote citizen science at different institutions; the two initiatives organize an annual citizen science conference hosted by different institutions. This way, new stakeholders come into contact with the topic and become aware of the possibilities citizen science brings (Hecker et al., 2018). Similarly, the German national platform “Bürger schaffen Wissen”, as part of the German capacity building program “GEWISS”, together with participants from various organizations, including scientific institutions developed a citizen science strategy for 2020 for Germany. They engaged in an “open, iterative and transparent consultation process” to “facilitate ownership” of the stakeholder groups. The integration of various forms of citizen science, including co-created citizen science projects, is one of the priorities defined in the 2020 strategy (Hecker et al., 2018). With increased buy-in from research institutions, researchers conducting citizen science projects could potentially receive more support from affiliate organizations in the future. However, the efforts are not directed at citizen-science in general and is not dedicated to co-creation.

To conclude, platforms offer solutions to the identified organizational level barriers. The results are summarized in Table 5 below.

Level	Barriers in (co-created) citizen science	Platform-based solutions
Organization	*Resource and infrastructure constraints*	
	Resource constraints (e.g. human resources)	– Provision of supportive functions, i.e. project builders as alternative to hiring developers
	Inadequate infrastructure (e.g. technology)	– Provision of cyber infrastructure to store, manage, and process data
	Strategy and mission	
	Unaligned mission	– Advocates for citizen science (national platforms)

Table 5: Platform-based solutions to organizational level barriers

4.9 Ecosystem level barriers

The researcher’s external environment may create ecosystem level barriers. Barriers on this level originate from the nature of the traditional science system, the scientific community and the unsophisticated knowledge systems with regard to co-creation, as well as funding agencies, and governmental policies, regulations, and laws

Traditional science system: The traditional science system discourages the pursuit of co-created citizen science (e.g. Hecker et al., 2018; Mckinley, Briggs, & Bartuska, 2015). Firstly, the traditional incentive and performance evaluation system in academia discourages citizen science, and especially co-created citizen science as it is a more extreme form (Hecker et al., 2018; Rotman et al., 2012b; Sui, 2014). The system rewards publishing in peer-reviewed journals and obtaining research grants but rewards activities such as community outreach or citizen engagement far less (De Rond & Miller, 2005; McKinley et al., 2017; Shanley & López, 2009). Some researchers argue that the reward received from engaging in citizen science is insufficient to make up for the costs such as extensive time investments. This creates an incentive gap that is particularly pronounced in co-created citizen science where investments are higher than in lower forms of citizen science (De Rond & Miller, 2005; McKinley et al., 2017; Shanley & López, 2009).

Similarly, the current scientific incentive system discourages disclosure of intermediary scientific results. Sharing (intermediate) results is perceived as a "competitive disadvantage" because it may help other competitive researchers to publish their research first, and thereby jeopardizing promotion opportunities, access to continued research funding, and employment security (Franzoni & Sauermann, 2014; Haklay, 2015; Paula, 2012). This is problematic because sharing of information is required in citizen science projects (e.g. Franzoni & Sauermann, 2014). It could be especially problematic in co-created citizen science projects where the scientific problem-solving and knowledge production process is opened to the public as well as competitive research teams.

Also, the science project culture is driven by competitive dynamics and a need for efficiency gains. Short term contracts, tight deadlines and limited research budgets that do not account for the costs of involving citizens in research reduce the possibilities of engaging citizens deeper in research (Thompson et al., 2009b; Ward et al., 2010).

Lack of acceptance from the scientific community: Scholars highlight that researchers undertaking citizen science projects still lack acceptance from the scientific community (Franzoni & Sauermann, 2014; Riesch & Potter, 2014). The scientific community questions the quality of citizen's contributions (Bonney et al., 2014; Riesch & Potter, 2014). In addition, researchers can find it difficult to publish citizen science studies in peer reviewed journals and have troubles finding scientific co-workers to support a project (Riesch & Potter, 2014). A lack of acceptance from peers could therefore discourage researchers to transition to co-created citizen science.

Lack of knowledge and best practices: Another barrier to transitioning to co-creation is researcher's lack of knowledge and best practices on co-creating research with citizens (e.g. Hecker, Haklay, et al., 2018; McKinley et al., 2017c; Schäfer & Kieslinger, 2016). Researchers engaging in citizen science have expressed the need for greater information exchange among scientists, asking for the establishment of best practices and standards for different project types. Topics of interest include how to achieve high data quality, how to handle intellectual property issues, and the question of which technical tools are available (Schäfer & Kieslinger, 2016a). Additional questions arise in co-created citizen science such as the acknowledgement of citizens' in scientific publications by offering co-authorship. However, there is no standard way to do this (e.g. Franzoni & Sauermann, 2014; Riesch & Potter, 2014). In summary, the lack of best-practice knowledge hinders researchers from pursuing co-created citizen science.

Insufficient (financial) support from funding agencies: Another barrier to transitioning to co-created citizen science is a lack of support from funding ministries and agencies (e.g. Hecker, Bonney, et al., 2018; Mckinley, Briggs, & Bartuska, 2012; Maria C. Powell & Colin, 2008). Funding agencies require researchers to submit structured, precise and goal-oriented research proposals in which the study concept and design are predefined (Thompson et al., 2009). In co-created citizen science projects, the research concept is typically not clearly defined from the start, and study aims may be adjusted during the research process, and study outcomes can often not easily be measured through traditional performance indicators (Hecker, Bonney, et al., 2018). Thus, a lack of funding due to a mismatch could make it difficult that co-created citizen science activities can be launched and continued.

Governmental policies, regulations, and laws: Governmental laws, policies, and regulations can make it increasingly difficult for researchers to engage in citizen science (McKinley et al., 2017b; Sui, 2014). Project owners need to pay careful attention to federal laws to avoid ethical and legal violations (Ballard et al., 2018). Citizen science projects must comply with legal and ethical rules related to data protection and privacy. Data privacy concerns apply to contributory and co-created citizen science projects that use digital devices that can capture participants' personal data. For example, mobile technologies may provide access to participants' sensitive data such as the geographical location, videos, photographs or audio recordings (McKinley et al., 2017). Hence, project teams must account for privacy-related concerns in the technical development of citizen science software and be able to deal with unprecedented or unexpected privacy issues (Preece, 2016). Additionally, the data collected by citizens must comply with data protection rules. For example, social sciences projects may face methodological and ethical risks if the collection of sensitive data does not follow ethical standards (Purdam, 2014). In difference to installing legal procedures in contributory projects, in co-created citizen science projects this may not be a trivial process. The openness of co-created citizen science raises new legal questions regarding participant's confidentiality, intellectual property rights or data ownership.

To conclude, there are several challenges on the ecosystem level, such as the traditional science incentive system, or a lack of knowledge and best practices, among others.

4.10 Platform based solutions to ecosystem level barriers

This section outlines platform-based solutions to ecosystem level barriers which include barriers arising from the science system, the scientific community, a lack of knowledge best practices, insufficient support from funding agencies, and governmental, policies, regulations, and laws.

Solutions to barriers of the traditional science system: An ecosystem barrier is the traditional science incentive and reward structure that discriminates against co-created citizen science. While a system change is needed to change the systems' fundamentals, platforms help researchers cope when they are reluctant to share intermediate results openly (Dasgupta & David, 1994). In many cases, intermediate results are only shared between members of the research team but not with the general public (Stephan, n.d.). Crowdsourcing (contest) platforms such as InnoCentive offer very secure solutions to researchers who do not want to publicly disclose intermediate results (Franzoni & Sauermann, 2014). These platforms usually target commercial organizations that aim to gain a competitive advantage by accessing research results and new technologies. For this reason, they ensure that high levels of anonymity and confidentiality are maintained. For example, before being able to participate, contributors must accept confidentiality and intellectual property agreements. Layered architectures also help to control which parties can access data and other study-related information (Franzoni & Sauermann, 2014b; Jeppesen & Lakhani, 2010). It would be possible to use a crowdsourcing (contest) platform such as InnoCentive to support a co-creation process; researchers would only have to share information with citizens involved in the project. Other platforms also offer researchers discretion and protection. On the hosting platform Zooniverse, citizens must login and agree to terms and conditions (which include privacy statements) for participation. However, such solutions are not as far-reaching as those of crowdsourcing (contest) platforms (Franzoni & Sauermann, 2014).

Solutions to lack of acceptance from scientific community: Another external environment barrier is that the scientific community does not sufficiently accept and support citizen science. Platforms help to enhance the credibility and acceptance of (co-created) citizen science among the scientific community by reducing skepticism on the quality of citizen contributions by providing technological solutions, training and education of citizens help that ensure scientific rigor and high quality of data, as elaborated on before (e.g. Hecker, Bonney, et al., 2018; See et al., 2016).

Solutions to a lack of knowledge and best practices: Some platforms create greater visibility of citizen science activities and promote the understanding of citizen science as a field. This helps to increase credibility and acceptance of citizen science but also builds knowledge and best practices. As already said, national listing platforms are successful advocates for citizen science (Kieslinger et al., 2018). In addition to facilitating buy-in from research organizations, national listing platforms are facilitating growth of citizen science in science, policy, and the society by publishing policy documents, white papers and practical resources such as training materials, videos, and best-practice guides online. By studying and analyzing different citizen science activities, they also contribute to the knowledge in the field (Bela et al., 2016; Bonney et al., 2014a; Susanne Hecker, Bonney, et al., 2018; Kieslinger et al., 2018; Pettibone et al., 2018; Pocock et al., 2014).

Some platforms function as resource and support centers. Hosting platforms and national and global project listing platforms, e.g. SciStarter and Zooniverse, commonly provide tools and best practice guides on setting up successful citizen science projects (Newman et al., 2012). They demonstrate the scientific benefits of citizen science by compiling success stories on well-managed citizen science projects (e.g. Zooniverse has shared insights into the Galaxy Zoo project). Through the sharing of such information, the platforms facilitate researchers to incorporate best practices in projects and produce potential new positive case examples to share later on. These efforts can increase credibility of citizen science in the long-term (Hecker, Bonney, et al., 2018).

The above examples show that platforms engage in activities to increase the credibility and awareness of citizen science. However, little is done to increase the credibility and awareness of collaborative and specifically co-created citizen science (Ballard et al., 2018; Kieslinger et al., 2018). As a result, scholars have called for expanded efforts and investments to increase knowledge on the practice and impacts of these forms of citizen science (Ballard et al., 2018; Kieslinger et al., 2018). One approach to achieve this could to enable more peer-exchange or exchange across the community of citizen science practitioners (e.g. Heinisch & Seltmann, 2018). Citizen science platforms and capacity-building programmes have already started to make an effort to establish communities to improve the exchange of knowledge between members of the citizen science community (e.g. Hecker, Bonney, et al., 2018; Kieslinger et al., 2018; Storksdieck et al., 2016). However, a workshop during the Austrian Citizen Science Conference 2018 revealed that cooperation and informal exchange between citizen science projects could be improved. Researchers voiced the need for creating a dedicated platform to improve collaboration between citizen science projects, which would enable the exchange of ideas, best-practices, experiences, lessons learnt, and finding collaboration partners (Heinisch & Seltmann, 2018).

Solutions to insufficient (financial) support from funding agencies: The ecosystem barrier of insufficient funding from funding agencies and ministries is frequently cited. Insufficient funding is a common problem for citizen science researchers (e.g. Harnack & Bauhus, 2018). Especially co-created research is discouraged by traditional funding agencies, which demand structured approaches that result in secure outputs; and co-created processes cannot typically ensure this (Schäfer & Kieslinger, 2016a). To increase support from funding agencies for citizen science, scholars have recommended to make agencies aware of the benefits and challenges of citizen science. They have suggested to tailor evaluation criteria to citizen science and include criteria such as social impact and engagement (Hecker, Bonney, et al., 2018; Kieslinger et al., 2018). Some have called for funding agencies to apply a more open-minded approach which allows for “scoping phases and openness to possible changes in direction or alignment of scientific and societal goals" (Hecker, Bonney, et al., 2018, p. 7). Platforms address these points in part. As outlined before, platforms are creating greater visibility and understanding of citizen science. It can be expected that greater visibility of citizen science projects and their impact, funding agencies will pay more attention towards the field. However, it seems that direct interaction and lobbying is needed in addition to providing information (Göbel et al., 2017). Some platforms have indeed directly impacted the availability of funding. Stakeholders of the national listing platform 'Österreich forscht' for example have been involved in initiating citizen science funding schemes in Austria (Kieslinger et al., 2018).

Besides removing barriers related to a lack of funding, platforms can also (partially) reduce the dependence of researchers on funding for a citizen science project. Some platforms, infrastructures and tools can be used and altered by citizen science project teams for free which eases financial burdens placed on project teams. As mentioned before, Zooniverse is free platform suited for classification tasks (Lichten et al., 2018). Another example is the platform and database called eBird. Researchers who study bird populations can save money as the platform enables citizens to upload observations to the eBird online database via the eBird app, and then the researchers can download data from the database for free (Bonney et al., 2014). The platform also allows researchers to adjust the tool to their needs, e.g. according to a specific region or data collection processes (Bonney et al., 2014).

Platform intermediaries can also ease financial burdens placed on citizen science project teams who need up-to-date tools such as apps. Product-service platforms can help ease the financial burden by allowing several projects to cooperate and share features (e.g. Hummer & Niedermeyer, 2018). An example is CitSci.org which develops technical solutions for citizen science projects for natural resource management. The platform assesses technical needs of projects, and tests, evaluates and refines solutions to develop a reusable, customizable software that can be used by many project(McKinley et al., 2017). Another example is the platform SPOTTERON which facilitates the collection of GEO-related data through customized apps. All apps share a common, basic system, and every new feature is developed with interchangeability and common use in mind. All extensions become available to all other projects immediately after the roll-out at no additional cost. According to the founders of the platform, synergy effects make SPOTTERON a financially attractive solution(Hummer & Niedermeyer, 2018a).

Solutions to barriers from governmental policies, regulations, and laws: Finally, project leaders face the ecosystem barrier of legal and ethical issues in setting up and managing a project. Project managers need to consider laws and policies, e.g. for copyright, intellectual property, or data protection (Ballard et al., 2018). Researchers can turn to platforms to address these issues. Platforms have developed systems that protect privacy of users through the system's design (Preece, 2016). For example, some platforms limit personal exchanges, introduce secure login procedures or offer secure data storage

(Harmon & Silberman, 2018; Preece, 2016). Other platforms ask participants to agree to terms of service and consent to privacy agreements. Foldit for example asks participants to agree that “the website and chat can be recorded” (Curtis, 2014). Ownership of intellectual property and copyrights can also be agreed upon upfront (Franzoni & Sauermann, 2014).

While these solutions look promising, scholars have suggested that platform-based solutions are limited. According to Mazumdar et al. (2017), more than just technical solutions are required to address data security and privacy concerns. Similarly, some platforms not only not solve ethical challenges but may even introduce ethical problems. Labor market platforms for example have been accused of supporting the exploitation of crowd workers (Pittman & Sheehan, 2016). This suggests that platforms do not fully help to cope with legal and ethical issues.

To conclude, platforms help cope with ecosystem level barriers, e.g. by offering mechanism to securely share intermediate results, or by providing tools and services to cope with limited financial resources. Further, they help to remove a lack of knowledge and best practices and provide technical infrastructures to comply with laws and regulations. However, platforms do not initiate system changes. The results are summarized in Table 6 below.

Level	Barriers in (co-created) citizen science	Platform-based solutions
Ecosystem	*Traditional science system*	
	Little reward for citizen science activities	No solution
	Discouragement of sharing of intermediate results	– (Securely) sharing of intermediate results
	Project culture focused on gaining efficiency	No solution
	Lack of acceptance from the scientific community	
	Quality concerns of the community	- Quality assurance mechanisms (see above)
	Challenges to publish in peer-reviewed journals	No solution
	Lack of knowledge and best practices	
	Lack of knowledge and best practices on co-creating research	– Advocates for citizen science (national platforms) – Resource and support center (hosting platforms)
	Insufficient (financial) support from funding agencies	

	Inflexible funding	– Increase visibility of citizen science as a field – Provision of free tools & services to reduce financial burden
	Governmental policies, regulations, and laws	
	Legal and ethical concerns, i.e. data privacy & protection	– Infrastructures to ensure compliance

Table 6: Platform-based solutions to ecosystem level barriers

5. Methodology

This chapter describes the research methodology chosen to shed light on the research questions. Building on the nature of the research problem, purpose and question, the authors decided to use a qualitative inductive-deductive multiple case study design, which is elaborated in the following. This chapter starts by presenting the research design and continues by elaborating on the processes of data sampling, data collection, pilot testing, and data analysis.

5.1 Research design

The research design decisions where taken with the research purpose of investigating a novel topic, advancing theoretical explanations and building theory for an understudied phenomenon (cf. Bingham & Eisenhardt, 2011; Ridder, 2017) in mind.

The research is both exploratory and descriptive in nature. It is fundamentally exploratory as it aims to explore a phenomenon for which scarce academic literature exists. Additionally, it tries to explain why researchers are not advancing to higher levels of engagement by investigating barriers to co-created citizen science. It is descriptive in some parts as it outlines and evaluates platform-based solutions (Thornhill, Saunders, & Lewis, 2009).

With respect to school of thought, this thesis adopts a pragmatist philosophy in a sense that they agree with researchers who argue that the most important determinant of the epistemology and ontology is the research question (Tashakkori & Teddlie, 1998; Thornhill et al., 2009). To investigate the barriers and solutions to transitioning to co-created citizen science, the authors apply a mixed ontological philosophy. They believe that behavior will be similar across social actors (i.e. researchers) (objectivism), however, they also acknowledge that social phenomena are shaped by the actors themselves; i.e. different interpretations of similar situations will affect one’s actions and interactions with others (subjectivism). With respect to epistemology, the authors aim at creating a theory that is generalizable across settings and thus try to approach the research in a largely value-free way (positivism). At the same time, the authors believe that interpretivism will make theory better in a sense that it will account for differences between human actors’ behavior and decision-making processes

(Eisenhardt, 1989; Thornhill et al., 2009). Thus, the authors cannot claim that the research is completely value free.

The research approach used to build theory is abductive (Alvesson & Sköldberg, 1994), meaning that inductive and deductive approaches are combined (Thornhill et al., 2009). An abductive approach was deemed appropriate for this study because there was a vast amount of literature in the field of citizen science that could help answer the research questions, while only very little literature covered the specific topics of interest. Consequently, existing theoretical research was reviewed to develop *pre-categories* (deductive) before the processes of sampling, collecting, and coding of data began (inductive) (Brytting, 1990; Eisenhardt, 1989; Gehman et al., 2018; Glaser & Strauss, 1967; Jensen, 1998; Skytte, 1992; Thornhill et al., 2009). This approach allowed the authors to become *aware* of a number of dimensions of the phenomenon to be studied and *discover* new dimensions (Perry & Jensen, 2001).

To elucidate the barriers and solutions to transitioning to co-creation, a qualitative multiple case study design based on a modified grounded theory approach was chosen as the research strategy. Qualitative case studies are well suited to elucidate a phenomenon that is only partially understood (Darke, Shanks, & Broadbent, 1998; Ridder, 2017; Yin, 2017). They are fit to answer *how* and *why* questions (Glaser & Strauss, 1967), assess causation (Lucrezi et al., 2018; M. B. Miles, Huberman, & Saldaña, 2014), and shed light on context-dependent knowledge (Andersen & Kragh, 2010; Flyvbjerg, 2006; Morris & Wood, 1991). A multiple case study design was chosen to enable a cross-case analysis to develop a deeper understanding of a phenomenon (Eisenhardt, 1991; Numagami, 1998) and increase generalizability (Eisenhardt, 1989). Since the purpose of this research is to answer the research question for a variety of cases (i.e. multiple researchers and their projects) rather than one case, the aforementioned strategy was chosen in this thesis.

Due to time constraints, this study is cross-sectional, i.e. it studies a phenomenon at a particular point in time (Thornhill et al., 2009). Further, the authors decided to conduct a multi-method qualitative study (Thornhill et al., 2009). While the preferred data source for primary data collection was semi-structured interviews, some data was collected through questionnaires and written conversations due to limited availability of the parties inquired. For triangulation purposes, primary and secondary data on each case was collected.

The techniques and procedures for the execution of the research strategy are further elaborated on in the following section.

5.2 Data sampling

In case study research, theoretical (non-random) sampling is the recommended sampling technique. This means that cases should be selected purposefully and for theoretical reasons, i.e. to replicate or extend theory (Eisenhardt & Graebner, 2007; See et al., 2016; Yin, 1994). In line with this common approach, this thesis uses *purposive sampling* to select multiple case studies that are particularly informative with regards to the research question (Thornhill et al., 2009).

As suggested by (Eisenhardt, 1989), the authors of this thesis planned the number of distinct cases for their sample. Eisenhardt, (1989) recommends selecting four to ten cases to have enough information to generate an empirically-sound theory but to also not be overwhelmed by the complexity and volume of the data. During the research process, the authors carefully weighed their goal of achieving theoretical saturation with resource (i.e. time) constraints. They set up additional interviews to gain new insights but also removed less insightful interviews or cases from their sample.[2] Section 4.3 elaborates more on the data collection.

As citizen science projects vary significantly (Franzoni & Sauermann, 2014b), it was clear that it would be beneficial to apply a maximum variation or heterogeneous sampling strategy which implies selecting more rather than fewer cases. This strategy allows to describe and explain central themes across cases with variation (Patton, 2002; Thornhill et al., 2009).

To construct the sample that would shed light on the barriers to transitioning to co-created citizen science, cases were distinguished based on predetermined dimensions, while keeping other characteristics constant (Eisenhardt, 1989; Eisenhardt & Graebner, 2007; Patton, 2002). The characteristics kept constant across all cases are the ones inherent to the definition of crowdsourced citizen science in this thesis. That is, all projects must involve a crowd, a researcher as the crowdsourcer, a task in the research process that is actively performed by the crowd, participation as defined by the crowd using its cognitive abilities and/or knowledge assets, research outputs that are jointly produced, and an open call.

To identify and select distinct cases, the authors distinguished the cases from each other by the extent of citizen power (or control) that the crowd receives in determining the end product of the research process. This is defined by two dimensions, i.e. the decision-making responsibilities that the crowd receives (cf. Arnstein, 1969), and the number of research phases that the crowd completes tasks in. To be considered “task completion”, a research task had to be completed by citizens. To be considered “decision-making”, decisions about research related matters had to be (actively) shared with or made by citizens. Note that during sampling, for purposes of simplicity, consultation and collection of feedback where citizens influenced decisions while not actively making decisions were not considered decision-making. The sharing of small or unimportant decisions was also treated as having no decision-making rights. An example is to let citizens pick the exact time of data collection within a predetermined

[2] To maintain high data validity (Saunders et al., 2009), four interviews were removed from the sample. One barrier interview was removed because of a highly unstructured nature. Another was considered unsuitable because it was launched in the early 2000s and is not representative for a contemporary analysis. Two cases were removed because the interviewers could not verify the interviewees’ responses. Because the interviewees were not researchers, they could not provide answers with certainty and further interviews with team members could not be scheduled.

time frame. These nuances were however documented ex-post of the sampling process. Examples of tasks and decisions in the research process are shown in Table 7.

	Conceptual phase*	Design and planning phase*	Empirical phase*	Analysis phase*	Writing phase*	Dissemination phase*
Task (Examples)	Formulating possible alternative research problems, purposes, and research questions (e.g. brainstorming)	Evaluating different research designs & procedures Developing the initial study procedures Determining the data sampling and collection plan (if applicable)	Developing study materials Sampling data Collecting data Processing data for analysis	Analyzing data Interpreting results	Writing a report	Communicating and/or publishing results (e.g. making a blog post, hand-in paper to a journal, speaking at a conference)
Decision (Examples)	Choosing the research problem and purpose Defining the research question	Selecting a research design Choosing a study procedure and data collection & sampling plan Selecting a technology Definition of financial, material, and personal needs	Specifying study procedure, data collection & sampling plan Specifying needs for study materials Specifying needs for data processing	Specifying analytical methods for data analysis and interpretation methods	Choosing the content, structure and set-up of what is to be written	Selecting the medium on which findings should be published Selecting authorship of the published result

*Order of the phases can be shifted in time

Table 7: Examples of research tasks and decisions in respective research phases

Considering the limited time frame of the study, the authors started by selecting “polar types”, i.e. extreme cases at opposite ends of each continuum (i.e. extent of decision-making power and number of phases citizens complete tasks in) (Mills, Durepos, & Wiebe, 2010). This is an effective approach for clear pattern recognition and the identification of relationships within the field of study (Eisenhardt & Graebner, 2007) as it illuminates unusual and typical cases due to its information richness (Patton, 2002).

Based on the aforementioned dimensions, four extreme cases within the case spectrum were initially identified (cf. Figure 1):

A) Citizens complete tasks in only one phase and receive no or little decision-making power. This case represents classic (contributory) citizen science projects.
B) Citizens complete tasks in only one phase and receive high decision-making power; researchers and citizens engage in shared decision making. This case represents the shift in the extent of decision-making power needed to advance to co-created citizen science.
C) Citizens complete tasks in a high number of phases and receive low decision-making power; the researcher decides in fifty percent or more of the phases. This represents the shift in the number of phases needed to advance to co-created citizen science.

D) Citizens complete tasks in a high number of phases and receive high decision-making power; researchers and citizens engage in shared decision making in fifty percent or more of the phases. This represents co-created citizen science projects.

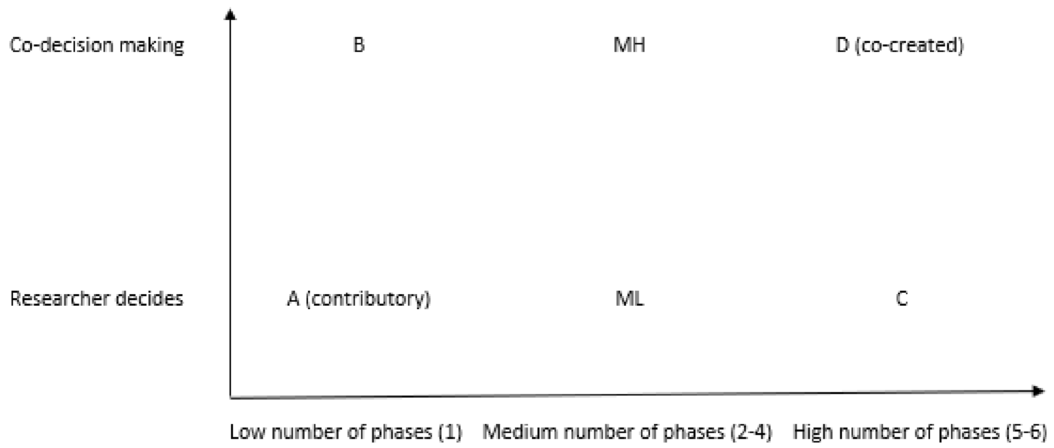

Figure 1: Case selection

Theoretical sampling, which is defined as “the purposeful selection of a sample according to the developing categories and emerging theories” (Cole, 1997) guided the sampling procedure. To illustrate, the authors initially selected extreme cases based on an ex-ante classification of research projects. After conducting an interview, each project was re-assessed to determine the *true* extent of citizen power (or control). Two more cases were identified:

ML) Citizens complete tasks in a medium number of phases and receive low decision-making power; the researcher decides in 50% or more of the phases.

MH) Citizens complete tasks in a medium number of phases and receive high decision-making power; researchers and citizens engage in shared decision making in fifty percent or more of the phases

During the research process, the authors scheduled further interviews to achieve theoretical saturation, maximum variation, and to fill missing gaps. Essentially, new interviews were scheduled to complement the existing data.

Data was collected from different sample groups of people (Patton, 1999; Timseena, 1970), i.e. researchers and non-researchers. This method helps to triangulate information because one-sided, intrinsic biases or distortion that might occur within one sample group can be compensated for (Patton, 1999; Timseena, 1970). For the sample of researchers, the authors searched for researchers who were conducting or had (successfully) conducted a citizen science project as defined above, or who aimed to but eventually did not conduct a citizen science project as defined above. As barriers may differ for research disciplines (Deutsche Forschungsgemeinschaft (Deutsche Forschungsgemeinschaft (DFG), 2017), the authors searched for projects conducted by researchers in diverse disciplines, ranging from the humanities and social sciences, to life sciences, or engineering sciences. Additionally, researchers with seniority levels, ranging from the highest (e.g. full professor) to the lowest grade (e.g. a PhD student) were sought-after to alleviate potential subject bias (Golden, 1992), ensure access to enough participants, and gain insights into the relationship of the employment status and behavior (Dick, 2017). Second, the authors searched for non-researchers who were involved in citizen science projects as defined above. Two project coordinators, one affiliated with an external partner organization and another employed by a university research support facility, were included in the sample. Platform stakeholders gave additional insights into the matter.

To construct the sample that would shed light on platform solutions, the authors searched for platform stakeholders internal and external to the organization. Stakeholders included platform representatives (e.g. employees), investigators and users who could outline the functionalities, benefits, and limitations of the respective platform. To ensure access to participants, the authors searched for platform representatives with different roles, e.g. founders, co-founders, project managers, and coordinators. Experts and platform users who are external to the platform organization could include members of the crowd or scientists who had conducted research on a particular platform, specific aspects of a platform, or several platforms of a platform type.

To systematically cover a broad range of functionalities across multiple platform solution providers (Neuman, 2005), a purposive (heterogeneous) sampling strategy was chosen (Thornhill et al., 2009). The authors based their platform sample on the seven distinct platform types previously identified in their literature search (e.g., Franzoni & Sauermann, 2014; Lichten, Ioppolo, D'Angelo, Simmons, & Morgan Jones, 2018). They also included bespoke platforms that were developed by a project team without a platform intermediary (cf. Brenton, von Gavel, Vogel, & Lecoq, 2018). The authors expected that they could gain insights into decision-making against working with a platform intermediary and thereby receive further insights into potential benefits and / or limitations of platform intermediaries. Seven cases were identified for the sample:

- Project hosting platforms that enable to create and host citizen science projects on an existing platform (Lichten et al., 2018);
- Project listing platforms that provide a listed overview of citizen science projects (Franzoni & Sauermann, 2014b; Lichten et al., 2018);
- Community engagement platforms that facilitate the direct collaboration between researchers, the crowd, and single crowd members (Bonn et al., 2018; Susanne Hecker, Bonney, et al., 2018; Mazumdar et al., 2018);
- Labor market platforms that enable to outsource tasks to a large crowd or individual freelancers (Franzoni & Sauermann, 2014b; Lichten et al., 2018);
- Crowdsourcing (contest) platforms that enable to outsource a clearly defined research task or problem to a crowd of problem solvers (Lichten et al., 2018);

- Product service providers that provide an existing technological infrastructure for citizen science projects (e.g., Hummer & Niedermeyer, 2018).
- Bespoke platforms in citizen science that are tailored to a particular citizen science project (Brenton et al., 2018).

5.3 Data collection

This thesis relies on primary and secondary data collection. The authors collected secondary data from peer-reviewed journal articles, working and conference papers, and books for the theory section of this paper. Furthermore, secondary data was collected to identify cases and participants and prepare for primary data collection. Newspaper articles, popular press, citizen science platforms, university and project websites were the main sources. In addition, one researcher contacted referred the authors to a similar study in which researchers from Copenhagen Business School had interviewed the interviewee already (cf. table 8, interview no. B17). The audio recording was obtained and transcribed by the authors in exchange for the use of the data.

Secondary data presents a key source for illuminating platform solutions. Secondary data on different platforms was collected in three phases, (1) an initially unstructured search to identify potentially relevant platforms for our platform sample, (2) a structured and focused search to develop a list of platforms that matched the seven platform types from the sample and (3) to gain a deeper understanding on each platform, the collection of information (e.g. key characteristics, functionalities) on each of the platforms. For the first and second phases, raw and compiled data was retrieved from academic sources such as peer-reviewed journals and non-academic sources such as popular press or project websites (Thornhill et al., 2009). In the third phase, raw data was collected from the respective platform organization’s website.

Bespoke platforms were excluded from the third phase of secondary data collection, as the authors identified that collecting and evaluating the functionalities and characteristics of bespoke platforms in their own right might be non-purposeful with regards to answering the research question. However, bespoke platforms were included in the primary data collection, as outlined in the following section.

<u>Primary data collection</u>

The primary data collection technique used in this study are semi-structured interviews which is typical for qualitative research (Thornhill et al., 2009), and questionnaires and written conversations when participants had limited availability.

For all interviews, a flexible interview guide rather than a script was used. Questions and topics were prepared by the authors beforehand, but the order of and the specific questions asked varied. Sometimes additional questions were asked, and some were omitted. This technique was chosen because it allows for a discussion with the interviewee, and gives interviewers the flexibility to adjust to the participants’ context, the flow of the conversation, build on responses and let an interviewee explain issues in more detail (Eisenhardt, 1989; Thornhill et al., 2009). This is prudent when adopting an interpretivist epistemology, as it helps to understand the meanings that participants ascribe to various phenomena (Thornhill et al., 2009). It also enables the exploration of new topic areas not previously considered; and represents a great benefit for an exploratory study (Eisenhardt, 1989; Thornhill et al., 2009).

A preliminary interview guide for illuminating the barriers to transitioning to co-created citizen science was prepared to conduct pilot interviews with researchers. As a result of the pilot interviews, the interview guide was optimized and finalized. The motivation to conduct pilot interviews and the subsequent changes to the interview guide are elaborated on in section 9.5. After completing the pilot interviews, the authors reached out to a larger group of people. Participants that matched the sampling criteria outlined in section 4.2 were identified via citizen science platforms (e.g. Zooniverse, Bürger schaffen Wissen), university and project websites, and referrals, and contacted via platform messaging systems, email, or personal endorsement as seen fit. The final sample of participants is shown in tables 8 and 9. Note that the projects were selected based on an ex-ante estimation of the citizen engagement, and the engagement was evaluated again after each interview (ex-post) (see table 9). The final sample consists of sixteen scientists and non-scientist project coordinators of the six different sample groups. It includes projects from various disciplines, ranging from those in which citizen science is common (e.g. biology), to those in which it is uncommon (e.g. medicine), and researchers of different seniority, and with affiliations to different types of research institutes. Further, projects were conducted in ten different countries[3] across Europe, North America, and Oceania. However, a great emphasis is placed on Europe due to the existence of a large quantity of citizen science platforms on this continent that allow for an ease of access to study participants. Project durations ranged from one year to indefinite, while most projects ran for about three years. Funding sources[4] included EU, government, university, foundation, and non-profit funds. Note that (1) in some projects (e.g. B1, B3, B4, B5, B17) different participant groups were involved in different research phases, (2) interviewee B16 is not part of sample of the six project types, and functioned as an expert, selected based on her affiliation with a citizen science journal, who provided a new perspective and triangulated results, (3) source no. B14-P6, B15-P8, and B8-P12 were researchers and platform stakeholders who were interviewed about both barriers and platform-based solutions, (4) B10 and B11 were researchers affiliated with the same citizen science project, and submitted survey responses, (5) B17 was obtained through secondary data.

Project #	**Source #**	**Ex-ante sample (ex-post analysis)**	**Project position***	**Seniority***	**Research institute***	**Discipline (Research area)***	**Platform type used**	**Interview date**	**Audio (mins)**	**VIVO codes**[5]

[3] This information is not shown in the table to maintain confidentiality of participants
[4] This information is not shown in the table to maintain confidentiality of participants
[5] Codes from interview transcripts and email conversations are added

1	B1	B (A)	Project coordinator	N/a (non-researcher)	N/a (NPO)	Humanities & Social Sciences (Humanities)	Product service	25.06	72	118
2.1 2.2 2.3	B2	D (failed D = B & MH)	Project coordinator	Low	Public	Humanities & Social Sciences (Humanities)	Project listing, Product service	04.07	82	163
3	B3	D (D)	Project lead	Medium	Private (non-profit)	Life Sciences (Medicine)	Project listing	09.07	75	138
4	B4	B (A)	Project lead	Medium	Public	Natural Sciences (Geosciences)	None	09.07	71	120
5	B5	B (MH)	Project lead	High	Public	Life Sciences (Medicine)	Project listing, bespoke	10.07	78	128
6	B6	A (ML)	Project lead	Medium	Public	Life Sciences (Biology)	Project hosting, bespoke	15.07	85	165
7	B7	A (ML)	Project coordinator	N/a (non-researcher)	Public	Engineering Sciences (Computer Sciences, Systems & Electrical Engineering)	Bespoke	23.07	103	92
8	B8-P12	A (A)	Project member	Low	Public	Natural Sciences (Physics)	Bespoke	31.07	65	97
9	B9	ML or C (C)	Project lead	High	Public	Humanities & Social Sciences (Social & Behavioral Sciences)	Project listing	09.08	82	137
10	B10	C or D (C)	Project lead	High	Public	Life Sciences (Medicine)	Project listing, bespoke	08.07	n/a[6]	56
10	B11	C or D (C)	Project member	Medium	Public	Life Sciences (Medicine)	Project listing, bespoke	29.08	n/a[7]	69
12	B13[8]	A (A)	Project lead	Medium	None	Life Sciences (Biology)	Bespoke	09.08	90	113
13	B14-P6	A	Project member	Low	Public	Life Sciences (Biology)	Community engagement	07.08	60	128
14	B15-P8	n/a (D)	Project lead	Medium	Public	Humanities & Social Sciences (Humanities)	Bespoke	13.08	160	204
n/a	B16	n/a	Expert	High	Public	Life Sciences (Biology)	N/a	12.08	72	
16	B17	B (ML)	Project lead	Medium	public	Humanities &	Project listing,	05.03	36	111

[6] Data collected via questionnaire
[7] Data collected via questionnaire
[8] Interview / source no. 12 was excluded from the sample to maintain high validity (Thornhill et al., 2009)

						Social Sciences (Social & Behavioral Sciences)	bespoke			

Table 8: Ex-ante Analysis Sample

			Research phases											
			Conceptual		**Study design and planning**		**Empirical**		**Analysis**		**Writing**		**Dissemination**	
Project no.	**Source no.**	**Project type**	**Task**	**Decision**	**Task**	**Decision**	**Task**	**Decision**	**Task**	**Decision**	**Task**	**Decision**	**Task**	**Decision**
1	B1	**A**				(*)	x	(x)						
2.1	B2	**B**	x	x	(f)	(f)	(f)	(f)	(f)	(f)	(f)	(f)	(f)	(f)
2.2	B2	**MH**					x	x	x					
2.3	B2	**D**	x	x	x	x	x	x	x	X	x	x	x	x
3	B3	**D**	x	x	x	(x)	x	x	x	(x)	x*	(*)	x	(*)
4	B4	**A**				(*)	x	(x)	(f)					
5	B5	**MH**	x	x	x	x	(o)		(*)	(*)				
6	B6	**ML**				(*)	x		x					(*)
7	B7	**ML**			x		x							
8	B8	**A**					x							
9	B9	**MH**				(*)	(o)	x	x	(x)	x	x	x	
10	B10 B11	**C**	x				x		x		x		x	
12	B13[9]	**A**					x	(x)						
13	B14-P6	**A**					x							
14	B15-P8	**D**	x	x		(*)	x	x	x	(*)	x	x	x	x
16	B17	**ML**				(*)	x	(x)	x				x	(x)

Table 9: Overview of cases (ex-post analysis)

Legend:

*Order of the phases does not have to be linear and could be shifted depending on the project

x: Research task completed by citizens (can involve some to all tasks in respective phase), and/or research decision about research related matters in particular phase shared with or made by citizens

(x): Non-critical research decisions shared with or made by citizens (without strong impact on the research study)

(*): Citizens are (passively) consulted or researcher collects feedback or suggestions from citizens (this includes that citizens can have an

[9] Interview / source no. 12 was excluded from the sample to maintain high validity (Thornhill et al., 2009)

influence on the decision with no active decision-making by citizens themselves)

(f): Citizen involvement in research task or decision making did not occur as planned (i.e. failed, not implemented as planned)

(o): Citizens collecting data about themselves, citizens as study objects

x*: Citizen involvement in research task or decision making is pending or not likely to happen (as expected by the authors based on statements made in the interview)

Empty: Citizens are not involved in task completion or decision making in the particular research phase

Participants were informed that they are contributing to a master thesis by students of the Copenhagen Business School in the field of citizen science. The students' supervisor names were shared to increase credibility, and interviewees were offered a copy of the final result as a sign of appreciation. All interviewees were asked to sign a consent form in which the terms of participation were agreed upon. All interviewees agreed to the terms, including strict confidentiality and an audio recording of the interview, among others. A template of the consent form can be found in appendix 8.8. Interviews were scheduled for sixty to ninety minutes to ensure that there would be enough time to gain deep insights. Because participants were dispersed, the interviews were conducted via Skype calls and, depending on the technical circumstances, included audio and video. Video calls were preferred, as they enable face-to-face interaction to encourage participants to talk freely and honestly (Mack, 2005).

Most of the interviews were conducted by two interviewers, with one main interviewer and one observer. The reason to choose this setup was to enable a conversation that puts respondents at ease by not making them feel interrogated (Leech, 2002), and to mitigate observer bias (Delbridge & Kirkpatrick, 1994). The supporting interviewer was able to observe and clarify potential misunderstandings or follow up on participant's responses that appeared ambiguous (Robson, 2002). A few interviews were conducted on a one-on-one basis due to inavailability or time constraints. To mitigate observer error (Thornhill et al., 2009), interview guides (cf. appendix 8.4) were used to structure the interviews (Krauss et al., 2009). At the beginning of an interview, the authors briefly introduced themselves and the research field (i.e. citizen science), reminded the interviewee about their consent (e.g. for the recording), and restated that anonymity would be ensured to mitigate subject or participant bias (Robson, 2002). Finally, a brief overview of the structure of the interview was provided before first questions were asked.

As recommended by Rubin & Rubin, (2011), interviews with researchers and non-researchers on the topic of barriers to co-created citizen science started with general questions to place the researcher and the project into context and continued with open ended questions followed by probing questions to identify barriers and potential solutions (i.e. floating prompts, McCracken, 1988). Open-ended questions have the advantage that one is able to identify barriers and solutions not identified by the authors before (i.e. inductive approach). Probing questions were used to restate a question for clarification, ask follow-up questions and verify factors previously identified in the literature (deductive approach) (Rubin & Rubin, 2011). They were also used to test newly identified factors from one interview in the following interviews with other interviewees.

To conduct the platform-interviews, platform stakeholders who fulfilled the sampling criteria (cf. section 4.2), were sought after on citizen science platforms, project or university websites, professional or social online networks (e.g. Linkedin, Facebook). Some were also identified through peer-reviewed journals. Stakeholders were contacted through e-mail or platform messaging systems. The final sample of participants is shown in table 9. It includes platform stakeholders, e.g. founders and project managers. Note that data from P9 and P10 was obtained via short written conversations.

Project no.	**Source no.**	**Platform type**	**Platform affiliation**	**Role**	**Interview date**	**Audio recording (minutes)**	**VIVO codes**[10]
1	P1	Project listing	Internal	Project manager	18.07.19	72	77
2	P2	Project listing	Internal	Project manager	29.07.19	90	101
3	P3	Labor market	External	Expert	31.07.19	60	28
4	P4	Project hosting	Internal	Project coordinator	01.08.19	116	108
5	P5	Crowdsourcing (contest)	Internal	Vice Pres. Bus. Dev.	06.08.19	49	16
6	B14-P6	Community engagement	External	Platform user	07.08.19	60	128
7	P7	Crowdsourcing (contest)	Internal	Co-Founder	08.08.19	63	66
8	B15-P8	Product service	Internal	Founder	13.08.19	160	204
9	P9[11]	Project listing	Internal	Founder	23.08.19	n/a	69
10	P10[12]	Labor market	External	Platform user	07.08.19	n/a	3

[10] Codes from interview transcripts and email conversations are added
[11] Data collected via questionnaire
[12] Data collected via written conversation

11	P11[13]	Bespoke	Internal	Project lead	13.08.19	n/a	5
12	B8-P12	Project hosting	Internal	Project member	31.07.19	65	97

Table 10: Primary data collection (Platforms)

The interviews with platform stakeholders were conducted after completing the interviews with researchers. Platform interviews focused on understanding the stakeholders' role, the platform's features and its intended benefits and limitations in reducing particular barriers to co-creation. An interview guide was used which built on the knowledge that the authors had gained from the interviews on barriers to transitioning to co-creation. Again, the interview guide was tested in a pilot interview before conducting the first interview. As the authors only made minor adjustments following the pilot (cf. section 4.4), the data gathered from the pilot interview was included in the sample.

Further, using an analogous structure for both interview guides enabled greater comparability of participant statements on barriers and solutions to co-creation and therefore, higher reliability (Harrell & Bradley, 2009).

For the interviews with bespoke platform stakeholders, the authors used an interview guide that combined parts from both interview guides. The authors expected that bespoke platform stakeholders were able to provide answers to both barriers and solutions, since the interviewees were researchers or project initiators who had decided to not collaborate with a platform intermediary.

All interviews were transcribed in clean verbatim shortly after each interview (Poland, 2011). Stutters, filler speech, most non-speech sounds, meaningless instances of words like "so" at the start of a sentence or conversational affirmations were edited out during transcription unless they added context or meaning to what had been said. Clean verbatim was chosen as a transcription style because this style conveys what has been said and does not alter the meaning of the content but makes transcripts easy to read and process (Poland, 2011). The transcription rules can be found in appendix 8.5.

5.4 Pilot testing

As touched upon in the previous section, pilot testing of the data collection technique was performed. The goal of the pilot testing was to improve the content validity and face validity and reliability of the interview by refining the interview guides so that the questions would answer the research questions, would be comprehensive, easy to understand and answered by participants (Hurst et al., 2015; Thornhill et al., 2009). As a result of the pretest, the interview guide was shortened, the order and structure of the questions were changed, some questions were removed or reformulated, and additional questions and visual aids added. Data analysis.

[13] Data collected via written conversation

5.5 Data analysis

The method used for qualitative data analysis is data coding which enables the development and refinement of interpretations of the gathered data (Charmaz, 2006; Saldana, 2009). In line with the abductive research approach (Alvesson & Sköldberg, 1994), a modified version of the grounded theory approach was used (J. M. Corbin & Strauss, 1990; King, 2004; Perry & Jensen, 2001; Saldana, 2009) which is more flexible than grounded theory (J. Corbin & Strauss, 2008) as it allows the inclusion of knowledge from existing theory in the analysis. It also mitigates concerns of obtaining insignificant results (Perry & Jensen, 2001; Thornhill et al., 2009). The authors used an analytical, qualitative software called "NVIVO" to code the text.

Scholars have recommended that when multiple researchers are involved in a research project, coding should be a collaborative effort (Erickson & Stull, 1997; Mac Queen & Guest, 2008). Thus, to ensure reliability (Thornhill et al., 2009) and group alignment, the researchers planned independent data coding followed by a result comparison (e.g. based on intercoder agreement; Russell Bernard, 2002) and discussion. The initial interviews were coded in this way until a common understanding was built. Due to time constraints, subsequently the researchers coded the sets of data separately but keeping in constant contact. They could ask each other questions and informed each other when they wanted to create a new category. Questions and potential new categories were immediately discussed. All coding was exchanged, reviewed, and discussed in daily meetings to reach group consensus (Harry, Sturges, & Klingner, 2005). To ensure consistency throughout the coding process, the authors kept a code book in which they documented the categories, their nature and scope. Working definitions and examples were used (Mac Queen & Guest, 2008; Saldana, 2009).

The coding process for the data gathered on barriers to co-creation was divided into first cycle and second cycle coding (Saldana, 2009). The analysis procedure of the first cycle coding was template analysis (King, 2004), and provisional, holistic, and descriptive coding (M. Miles & Huberman, 1994; Saldana, 2009). As indicated earlier, existing theoretical research was reviewed to develop pre-categories that served as a point of departure to develop a coding template (King, 2004). However, rather than including the pre-categories to test and verify pre-defined hypotheses, they were "put on trial within a real empirical context for contextual re-specification, refinement, or elimination." (Perry & Jensen, 2001). The pre-categories served as provisional categories which were revised, modified, deleted or expanded during the analysis process based on constant comparison of the data and emerging categories (M. Miles & Huberman, 1994).

The remaining coding was handled according to grounded theory-building processes (Glaser & Strauss, 1967), as recommended by (Perry & Jensen, 2001). An open coding process included holistic and descriptive coding to break the data into discrete parts of similar units (Saldana, 2009). Paragraphs were coded using nouns or short phrases to describe the topic (i.e. the "substance of the message") rather than the content. This was aimed at developing an understanding of the issues that were emerging from the data and to avoid getting overwhelmed (Dey, 1993; Tesch, 2013). When a paragraph contained information that matched several categories, it was coded into all. When the information did not fit an existing category, a new category was created. As new categories emerged, earlier transcripts were re-coded according to the updated list of categories. The following example of the coding illustrates the process. The extract below was coded into two categories, first the existing category "CIT - skills" (CIT is an abbreviation for citizens) and second, the newly created category "CIT - education".

Interviewer: Would you say that sometimes there is a lack of skills to do the tasks from the side of [citizens]?	CIT - skills
Interviewee: Yeah. As I said, we try to compensate that with some webinars, but it's clear that we can't do that in a sufficient way and it's only giving them certain insights that remain on the surface. (...) They can't bring the same skills as professional scientists.	CIT - education

Similarly, the coding process for data collected on platform solutions was divided into first and second cycle coding (Saldana, 2009). The analytical procedure of the first cycle coding was based on the data display and analysis approach (M. Miles & Huberman, 1994), first using descriptive and then process coding methods (J. Corbin & Strauss, 2008; Saldana, 2009). As previously outlined in the section on secondary data collection, the authors gathered information (e.g. key characteristics, functionalities) on each of the listed platforms and condensed the data into topic-based themes through developing descriptive categories (M. Miles & Huberman, 1994; Saldana, 2009). Categories were labeled through nouns that describe similar platform functionalities (Saldana, 2009). For example, the authors gathered all platform functionalities enabling communication between multiple parties such as group discussion forums, chats and comment sections in the category "Communication and group interaction". As the example shows, most categories were divided into broad themes to ensure a clear and distinct understanding of the categories. Non-assignable platform information was discussed and subsequently either allocated into one or several categories, depending on the fit, or placed into a new category. This method enabled the authors to structure similar content and condense the amount of data gathered as a first step of the first cycle coding (M. Miles & Huberman, 1994). In the second step of the first cycle coding, the authors refined the established categories by using process coding methods (J. Corbin & Strauss, 2008). By reviewing the actions of platform intermediaries towards solving barriers to co-creation in the previously established categories, process coding allowed the authors to verify if the established categories were purposeful selected (i.e. directed towards answering the research questions), contained a similar unit size and if content was correctly placed. For example, it showed that the established category "Communication and group interaction" covered a broad range of functionalities in which the corresponding platform offering included "providing information on the citizen science project", "creating outreach to citizens and/or public", "enabling to build a community" or "creating interaction among citizens and/or between researchers and citizens". In the particular example, the authors established properties to get a better understanding of the services that platform intermediaries provide for "facilitating communication with citizens and the public and enabling group interaction". Similarly, other established categories were reviewed and, if necessary, altered accordingly. After consolidating the data into their corresponding categories and properties (i.e. data reduction), the data from the first cycle was visualized in a matrix (i.e. data display) (M. Miles & Huberman, 1994). Platforms which could not be assigned to one specific platform type were either marked as hybrids in case that those platforms possessed characteristics of more than one platform type and therefore, were not clearly assignable, or put into 'Others'. The matrices enabled the authors to draw first conclusions on the diversity of platforms across and within a certain platform type, indicating which platform types might be more or less suitable to solve barriers to co-creation.

During second cycle coding on the data on barriers to co-creation, the data was reorganized and reanalyzed (Saldana, 2009). First, the content within each category was refined as recommended by (Rubin & Rubin, 2011). For example, versus coding was applied to refine the category "project type" to include four sub-categories (e.g. "small scale vs. large scale" projects) (Altrichter & Posch, 1993). A cross-category analysis followed. Focused coding was applied to revise categories, merge similar categories, and drop less important categories. This resulted in fewer categories that were suited to answer the research questions (Charmaz, 2006; Saldana, 2009). In a next step, the authors identified themes in the data by searching for relationships between the categories, as well as patterns and concepts (Thornhill et al., 2009). As recommended by Saldana, (2009), the authors took note of relations between different variables (categories) in an analytical memo. Further, properties were created to capture information with explanatory potential with regards to the research question. Short sentences that demonstrated the meaning of the data were used to capture themes (Boyatzis, 1998). This included capturing opinions, decisions, experiences, and expectations of interviewees, among other things. To enhance the credibility and quality of the work, the authors searched for alternative explanations and negative examples when a pattern or relationship emerged (M. Miles & Huberman, 1994; Patton, 1999). For example, when interviewees agreed that a certain factor was a barrier to transitioning to co-creation, the authors specifically searched for deviating evidence. Subsequently, two categories were created as in the example below.

Category: "RES - Characteristics - Seniority"

Interviewer: Have you experienced that people of certain seniority levels are more reluctant to co-create? *Interviewee: I don't think so. I don't think I've noticed any kind of trends with regards to seniority levels.*	Opinion - Seniority does not influence whether someone co-creates or not

I think you're getting in more problems if you are a beginner. Because you need – there're a lot of challenges you have to solve, you need to be flexible and kind of dynamic and innovative (..). I think you need some sort of seniority to be like this. (...) Seniority makes you (..) more relaxed and you have a better standing [among citizens].	Opinion - Co-Creation is harder for researchers of low seniority

In the second cycle coding on platform solutions, the authors included primary data gathered during the interviews with platform stakeholders. This enabled triangulation of the previously gathered secondary data to ensure high data validity (Thornhill et al., 2009). Using a template analysis approach (King, 2004), the authors added primary data to the coding structure established during the first cycle coding process. Non-assignable content was first holistically coded to explore additional themes that were not present in the established coding structure (Saldana, 2009) and subsequently refined by creating lower-order properties through process coding (J. Corbin & Strauss, 2008). Revising the existing and newly developed categories enabled the authors to identify important themes for answering the research questions (King, 2004). Further, while the former categories mainly highlighted platform benefits, e.g. “facilitating communication with citizens and the public, and enabling group interaction”, the authors established more neutral categories and added platform benefits and limitations as analogous second-order properties. An example is provided below.

Category: “Communication with citizens and the public and group interaction”

Interviewee: What we were really after is, kind of building a community and building this engagement and letting people talk to each other so that they can learn from each other. [...] The only place that really supports that kind of dialogue, it's Facebook.	Benefit - Enabling to build a community
Interviewee: Definitely just having a way to have a conversation because that's what I think is lacking on Twitter and Instagram.	Limitation - Not facilitating communication among citizens

Establishing affirmative and negative categories further ensured credibility by avoiding distortion of data to either positively or negatively biased views (Patton, 1999). As a result, the authors adjusted the former template hierarchy by adding, altering or dropping higher-order categories and respectively allocating second-order properties (i.e. platform benefits or limitations) to the changed hierarchy and establishing third-order properties to give explanatory power to the outlined second-order properties.

To assess the strength of a code, the authors assessed the frequency of codes to show how many of the interviewees believed a statement to be true. After the second cycle coding it became clear that no further higher-order categories had to be created. Newly created properties could be matched to the existing higher-order categories as they represented additional aspects or nuances within the existing categories.

After completion of the coding process, the assessment of each project with regards to the citizen involvement was shared with the interviewees via email to be verified.[14] The triangulation helped to ensure reliability of the analysis (Easterby-Smith, Thorpe, Jackson, & Lowe, 2008). In one case it provided the authors with a written discussion with the interviewee that provided new insights which were subsequently coded. The verified assessment of the cases is shown in the table 8 in the section above.

In a final step of the analysis, the authors used a pattern matching approach to develop a final framework. They compared the results from the empirical analysis with the theoretical framework derived from the literature (Yin, 2017). By providing evidence for predicted relationships, identifying new elements and relationships, the authors could contribute to theory building. By developing an analytical framework, the authors are also able to assess factors critical for solving particular barriers to co-creation and can therefore evaluate the suitability of certain platform types through their respective service offerings.

[14] All but one (B7) interviewees verified and confirmed the information. The authors did not receive a reply from B7 and could not follow-up due to time constraints.

Barrier			Relationships between categories (nodes) that make up the barrier						Consequence for transitioning to co-creation	
Type	**No.**	**Description**	**External environment**	**Discipline and scientific community**	**Project type**	**Group (team)**	**Researcher**	**Citizen**	**Task involvement is not expanded**	**Decision-making is not shared**
Will	R1	Researchers' perception of (co-created) citizen science and its uncertain nature		Discipline & study design	Research driven / socially driven		Perceptions, attitudes, etc.	Circumstances & demographics	x	x
Will	R2	Researchers career opportunities & desire to publish in peer reviewed journals	Science system	Scientific community	Research driven / socially driven Small scale vs. large scale		Perceptions, attitudes, etc. Seniority		x	x
Will	R3	Researcher's desire to adhere to good scientific practice		Scientific community	Research driven / socially driven		Perceptions, attitudes, etc. Seniority		x	x
Ability	R4	Researchers' lack of knowledge and skills		Discipline & study design Scientific community		Team size Team members	Knowledge & skills Perceptions, attitudes, etc.	Knowledge & skills	x	
Ability	R5	Citizen's lack of knowledge and skills (scientific literacy & domain knowledge)		Discipline & study design	Long-term vs. short-term	Team size Team members	Capacity (time) Knowledge & skills	Knowledge & skills	x	x
Ability	R6	Citizens' circumstances and demographics		Discipline & study design	Online vs. offline projects Long-term vs. short-term School project		Perceptions, attitudes, etc.	Engagement Circumstances & demographics	x	
Engagement & Team	R7	Expected (a) and experienced (b) lack of citizen engagement (Barrier to forming a team)	Society	Discipline & study design Scientific community	Research driven / socially driven Small scale vs. large scale		Knowledge & skills Perceptions, attitudes, etc.	Engagement	x	x
	R8	Diverging interests (Barrier to forming a team)			Research driven / socially driven		Perceptions, attitudes, etc.	Engagement Perceptions, attitudes, etc.	x	x
	R9	A lack of mutual trust & respect (Barrier to norming a team)	Funding agencies Society	Discipline & study design	Long-term vs. short-term		Perceptions, attitudes, etc. Capacity (time)	Engagement	x	x
	R10	Missing team spirit (Barrier to performing in the team)			Online vs. offline			Engagement Circumstances & demographics	x	
	R11	Barriers related to co-creating with a large crowd			Small scale vs. large scale Online vs. offline	Team size				x
Bureaucratic & administrative	R12	Researchers' limited capacity (time)				Team size Team members	Capacity (time) Seniority		x	
Bureaucratic & administrative	R13	Lack of sufficient, long-term, and flexible funding	Funding agencies Government		Research driven / socially driven Long-term vs. short-term		Seniority Perceptions, attitudes, etc. Capacity (time)		x	
Bureaucratic & administrative	R14	Legal and ethical barriers	Laws & ethics		Online vs. offline				x	
Bureaucratic & administrative	R15	Organizational barriers (theoretical saturation not reached)	Organization						x	x

Legend: **Dimensions:**

- External environment: a) Organization, b) Science system, c) Funding agencies, d) Government, e) Society, f) Laws & ethics
- Discipline & scientific community: a) Discipline & study design, b) Scientific community
- Project type: a) Small scale vs. large scale, b) Long-term vs. short-term, c) Online vs. offline, d) Research driven / socially driven, e) School project
- Group (team): a) Team size, b) Team members
- Researcher: a) Capacity (time), b) Knowledge & skills, c) Perceptions, attitudes, etc. d) Seniority
- Citizen: a) Engagement, b) Knowledge & skills, c) Circumstances & demographics

Table 11: Relationships between categories (nodes) that make up the barrier

6. Analysis

This section outlines barriers to transitioning to co-creation and presents potential solutions to mitigate or remove the barriers. It is structured according to five types of barriers and their respective solutions: Barriers of (1) will, and (2) ability of the researcher, and (3) of the citizen, (4) barriers to engagement and team development, and (5) bureaucratic and administrative barriers. Note that for confidentiality reasons, the pronoun "she" is used for both genders.

6.1 Barriers of will of researchers

This section presents barriers of will of the researcher that originate from researchers' perceptions, attitudes, beliefs and values and result in a researcher not *intending* to pursue co-creation.

Barrier of will (R1): Researchers' perceptions of (co-created) CS and its uncertain nature

Diverse motives to conduct CS: Interviewees indicated that the motives to do CS influenced whether researchers co-create or not. Interviewee B2 emphasized that researchers who perceived CS solely as a tool to facilitate or speed up science would not pursue co-creation. She believed that researchers pursuing co-creation follow social motives and perceive CS as an end. The analysis confirms this relationship. All researchers conducting A, ML, and C projects pursued scientific goals but did not pursue social goals. For example: *"For me CS is a way of getting data. [It] is another information source."* (B7, ML project). Only B1 (non-researcher, A project) followed social motives and supported researchers in conducting CS to foster dialogue between research and society. Some (7) of the researchers of A, ML, and C projects had educational or inspirational motives, e.g. aiming to increase citizens' scientific literacy.

Social motives were only present for researchers conducting higher forms of CS (B, MH, D projects). The researchers typically followed multiple goals, including scientific, educational, social, and CS-oriented goals. Interestingly, one researcher did not explicitly mention having scientific motives but highlighted a desire to conduct socially relevant research and contribute to CS as a research field:

> *"I thought that it would be a good idea to share research and the research process with citizens, to engage in dialogue, to talk with them on an equal level and to find a common language [...]. And, of course to advance research."* (B2, B / aspired D project)

This shows that the diversity of motives increases with the form of CS and that social motives are prominent at higher levels.

Perception of the usefulness and applicability of co-creation[15]*:* Most researchers conducting lower levels of CS acknowledged the usefulness of co-creation but found it either not applicable to their respective situation or found that it depended on other factors such as the research purpose or question. However, two researchers did not find co-creation useful. To illustrate:

"I totally agree about co-creation, but I feel that CS is not the way." (B7, ML project)

In contrast, MH project researchers believed that the usefulness and applicability depended on factors such as study type, and D project researchers were convinced about the usefulness but acknowledged that the applicability depended on external factors.

Attitude towards uncertainty and change: During the interviews (e.g. B16, P1), it emerged that due to the nature of co-creation projects, researchers need a positive attitude towards uncertainty and change. This includes the ability to be flexible, respond to the unexpected, give up some control and be relaxed about it. The expert illustrated this:

"In a [co-created] project [..] the scientists wouldn't know what it's going to ultimately look like. [...] I would think it'd be a rare scientist that would be comfortable truly co-creating something" (B16)

The interviews[16] were analyzed to find statements that signaled a researcher's openness towards uncertainty and change, for example: *"I want to have some kind of control over what is happening."* (B4, A project). It showed that researchers pursuing lower forms of CS were more reluctant to change than those pursuing higher forms.

Barrier of will (R2): Researchers' career opportunities and the desire to publish in peer reviewed journals

Unsupportive science system: One reason for researchers to decide not to co-create is based on personal career opportunities and the desire to publish in peer reviewed journals. The root cause of the problem is the science system, which discourages researchers to co-create. Twelve interviewees[17] agreed that the system presented a barrier. They highlighted imbalanced incentive systems which favor publishing in peer reviewed journals over outreach and citizen engagement activities, pointed to the fact that a formal career path for CS was missing, and said that even when CS activities are pursued, researchers struggle to measure and show their performance because evaluation systems are not in place.

Differences across disciplines: There is some evidence that there are bigger problems in disciplines in which CS is not yet established because the scientific community is skeptical of CS which makes

[15] Data from B10, B11, and B17 could not be obtained due to the nature of the data source. From two interviewees, only insights into usefulness or applicability could be gained.
[16] Data for interviewees B10, B11, B17 could not be obtained. Interviews B1, B13, B14-P6, B7, B8 did not show a tendency.
[17] None of the other interviewees disagreed. Data for B10, B11, B17 was not obtained due to the nature of the source.

publishing in peer reviewed journals harder. In line with this, three researchers in the humanities and social sciences, in which CS is uncommon, shared their negative experiences in the peer review processes, e.g.:

“I get these kinds of concerns back, like people telling me, this is not real science [...] (B15-P8, D project)

Another interviewee’s experience in the field neutralizes the above slightly. She was able to publish an article and had another one placed under review, having received an invitation to revise and resubmit the manuscript (B17). In contrast to the above, a researcher in the field of life sciences (biology) expressed that scholars were starting to acknowledge CS (B16). Similarly, a researcher in the life sciences (physics) had an article under review, expressing no concerns. Further evidence is however needed to draw certain conclusions, as other researchers had not tried to publish results yet.

Individual career opportunities: While the science system was undoubtedly described as a barrier, not all researchers felt discouraged by it. Further analysis showed that what kept some researchers from engaging citizens in more tasks, particularly in the conceptual and writing phase, was the way in which the individual dealt with the system. Three researchers with a focus on career opportunities highlighted the importance of publishing in peer reviewed journals (1x A, 2 x ML project), and stated that they feared that their personal career opportunities would be limited:

“I need to publish (..) in scientific peer review journals. I need to do it in time so that I can apply for other funding and so on.” (B6, ML project)

In contrast, researchers with lower career aspirations, or those who felt autonomous or who enjoyed trying new things, did not feel particularly hindered:

“I find my results very thrilling [...] so it doesn't really matter so much if I can communicate it to the scientific community” (B9, MH project)

“I don’t have high ambitions in terms of my career. [...] I’m doing this job because I like this flexibility.” (B3, D project)

Seniority and behavior: Two researchers suggested that a researcher’s seniority influenced behavior. They (B9, B15-P8) described how PhD students had felt discouraged by bad criticism in peer reviewed journals or by not having obtained results. The relationship between seniority and perception could however not be confirmed in the sample of this thesis since there were PhD students (e.g. B2) who pursued a co-creation project and said that despite experiencing challenges, she would do it again.

Barrier of will (R3): Researchers’ desire to adhere to good scientific practice

Ensuring scientific rigor by limiting the number of tasks: A similar problem is related to the desire of researchers to adhere to scientific standards. This desire was expressed by many researchers, including all of those with high career aspirations but also some without. Typically, researchers did not involve citizens in the design and planning phase to retain control over important research design decisions and to ensure the scientific rigor (cf. 9 researchers). The main reason for this is that citizens have insufficient scientific literacy (cf. barrier R5). One researcher highlighted how she rigorously planned every detail of the study:

> *"The research design was very important [...] I wanted everything to work out and wanted to make sure that it is not my fault when we don't get any results."*[18] (B17, ML project)

In some instances, citizens were involved in the design and planning phase. However, in two cases the researchers did so because they were testing a co-creation approach, and not because they thought that citizens could contribute value (B2, B3). In another case, it was a non-researcher who collected ideas from citizens to increase engagement but design decisions were taken researchers (B7). In the other cases, strategic decisions were shared with citizens to increase mutual trust (B5).

Ensuring scientific rigor by limiting decision rights: Researchers wanting to adhere to good scientific practice also tended to give citizens no or limited decision rights in the design and planning, empirical and analysis phase, in which scientific literacy is important. Commonly researchers took decisions and provided clear instructions or guidelines, some tried to reduce potential mistakes by designing a restrictive digital interface (e.g. app):

> *"Clear guidelines / rules / requirements must be set by the researchers for the citizens and compliance must be checked (at least randomly). Keyword: good scientific practice"* (B11, C project)

When citizens were involved in decision-making in the design and planning phase, there were typically only a few involved citizens. Five projects consulted teachers to evaluate the feasibility of the tasks to be completed by students. Again, two projects only involved citizens in decision-making because they were testing the feasibility of co-creation approach. When citizens were involved in decision-making in the empirical and analysis phases, mostly, the decisions did not have a large impact on the study results. For example, one researcher allowed citizens to choose the specific time to collect data while predetermining the time frame that would allow for good scientific results. The other projects were testing a co-creation (B2, B project; B3, D project), and a new methodological approach (B9, MH project). There was one researcher who did not have any quality assurance mechanisms in place and who provided full freedom to citizens in the empirical phase. She stated:

> *"I have not so [many] concerns when it comes to methodology." (B15-P8, D Project).*

[18] This text extract was translated from German to English by the authors

Seniority and behavior: Two researchers (B2, B7) believed that more senior researchers were reluctant to engage citizens in research and suggested that this might be due to senior researchers devaluing citizen contributions as being of lower quality. However, the authors could not identify a conclusive pattern in their data.

6.2 Solutions to barriers of will of researchers

Solution to barrier of will (R1): Researchers' perception of (co-created) CS and its uncertain nature

Facilitate formal and informal knowledge exchange: The interviews revealed that barriers related to researchers' perceptions on (co-created) CS may be overcome by adjusting these differences using formal and informal knowledge exchange. The following statement supports this:

> *"One of our assumptions [...] was to test whether the co-creation approach would actually work in [our field of] research. [Retrospectively] resources would be very important and knowledge on how to do CS in [our research field], or co-creation in [our research field].*" (B2, B / aspired D project)

With regards to platform solutions, the interviews showed that hosting and listing platforms foster knowledge exchange to enable changes to researchers' mindsets. Hosting platforms facilitate the creation and management of CS projects. Three of five investigated hosting platforms showcase the impact and validity by publishing citizen-science findings, results and best practices. Interviewee P4 outlined this, but also added that improvements are still needed:

> *"[...] we can show how accurate the idea of CS is. [...] That can really help with this acceptance problem [...] In the past we've produced blog posts and papers about how we think CS should be produced or a CS projects should be run. We do have a lot of opinions [..] but we could perhaps do better at really formalizing them and sharing them in a way with the wider community [...]."* (P4, hosting platform)

Listing platforms promote projects within the CS community and to potential participants. The interviews show that three out of five listing platforms provided educational services by sharing CS knowledge. No data could be obtained for the other two. Two of the five listing platforms organized CS campaigns and conferences to help project initiators. Platform stakeholder P2 also highlighted that conferences help form an open-minded community:

> *"[...] our conferences are more open-minded [than in traditional science], you can ask questions and you're really welcomed into this community. [..] They all have one goal, to make more open science"* (P2; project listing platform)

It is still unclear whether these platform mechanisms to educate CS researchers have had an effect on researcher's perception towards co-creation.

Making CS known across domains: Hosting platforms and listing platforms try to change researcher's perceptions by making project information visible to researchers in different research fields. A representative of a hosting platform (P4) highlights:

> *"[...] sometimes time and quantity of CS projects can help. In astronomy CS is completely accepted [...] now. [...] Whereas in biomedical sciences [...] there's still more skepticism [...]. Part of it is just the field itself like how old is the idea of CS in that field? How many projects have been run? How many papers have been published?"* (P4, hosting platform)

B2 explained her motivation to use a project listing platform:

" [...] we want to be visible, [...] to raise awareness for our topic and also to show that there is CS done in the humanities." (B2, B / aspired D project)

The analysis showed that labor and crowdsourcing platforms do not offer any solutions in this regard. Additionally, no solutions to aligning perceptions were found in engagement and service platforms. While labor platforms help researchers to outsource defined tasks to a crowd or (specialized) individuals against payment, crowdsourcing platforms help researchers to systematically process solutions for idea generation and / or issue resolution, improve consensus building and coordination. Analysis of five labor and six crowdsourcing platforms shows that both platform types are commercially focused and therefore address a target group other than initiators of CS projects. This was also confirmed by three interviewees (P3, P5, B16). For example, P5 states:

> *"That's for their own commercial uses. Sometimes, there could be an element of doing that for research purposes. [...] But that's actually quite rare."* (P5, crowdsourcing platform)

Data on the support of engagement and service platforms on aligning researcher's perceptions did not provide any solutions.

Solution to barrier of will (R2): Researchers' career opportunities and the desire to publish in peer reviewed journals

Reward CS activities: Two interviewees (B2; B8) voiced the need of changing the science incentive system. One highlighted that the system should acknowledge science communication, CS and outreach events performed by researchers more (B2). The other emphasized the need to change performance evaluation mechanisms to evaluate the social impact of research on society, and measuring the research performance (B8). Overall, there is strong agreement among interviewees that as long as the science incentive system does not change, researchers will be discouraged from CS activities (e.g. B16, B9, P2, P4).

Besides the required solutions stated by researchers, the authors did not identify platform solutions that can directly provoke a change in the current science incentive system or academic career paths. The data shows that no platforms offer solutions to changing the scientific reward system. However, one platform hosting representative (P4) stated that alternative ways to change the system should be considered. One provider offers CS project researchers the opportunity to publish using the platform infrastructure thereby decoupling publication from the traditional system. Such alternative infrastructures for publishing provide alternative or non-traditional reward mechanisms:

"We should be looking at non-traditional ways of engaging the government, engaging the scientific community and the research that's being done, whether that's by our own new journals, [or] by social media which is very big in CS because public engagement is such a high part of it." (P4, hosting platform).

The interviewee did not further outline how alternative ways of disseminating scientific work could be aligned with researchers' desire to improve their own academic careers.

Promote CS in the science community: The interviews show that, although platforms cannot directly change the science system, they can influence on it. Specifically, project listing platforms address the urge to change the current science system by cooperating with and lobbying among various stakeholders. Three interviewees (P1, P2, P9) stated that they cooperate with various external stakeholders such as public authorities, universities, non-governmental and private organizations to promote the "benefits of working with CS" (P9) and leverage CS as a field. This concurs with the suggestion of one researcher to establish partnerships and network with CS associations (B2).

In that sense, two project listing stakeholders (P2, P9) mentioned that they do 'lobby' work to achieve greater awareness and acceptance of CS. For example, according to P9, lobby work included convincing research institutions of the "benefits of working with CS". In this regard, P2 highlighted that creating networks (among researchers) and lobbying form rather smaller steps to achieve long-term change:

"It's a lot of little steps we can help the initiators and the researchers to make it more acceptable or accepted into their institutions. But there's not [...] (a single) solution." (P2, project listing platform)

The analysis of five of each of the service and engagement platforms shows that they provide more implicit solutions by showcasing the value and impact of CS. Service platforms offer to develop, provide and maintain a (standardized) technical infrastructure for researcher's CS project. In comparison, engagement platforms help users to communicate, share and exchange information among group members. The authors analyzed five platforms of each category. It showed that, while not all platforms of one type were applicable, some platforms could be used to promote CS.

For example, a researcher used engagement platforms for CS (P6) and stated that that they generally do not provide a solution to promote CS among science system decision-makers but that some could still be used as a means to document the impact of CS:

"The lack of acceptance, I don't really see how [the platform] can help [...]. I think that's just something that's going to come with time and successful projects. [...] But [...], just documenting those successful projects [...], promoting it with others and getting the word out there to others." (P6, engagement platform)

Lastly, stakeholders belonging to labor and crowdsourcing platform stakeholders were not able to provide a clear answer on the support offered to promote CS among the scientific community. They generally highlighted that the solutions of both providers might not be suitable to support CS, e.g.:

"In terms of lack of [peer] acceptance, I don't know if – I guess, (that) just by participating in the market we're helping to build the acceptance for it [however] It does not sufficiently support CS especially at deeper citizen engagement levels." (P7, crowdsourcing platform)

Solution (R3): Ensure methodological rigor and shared decision-making

Explore new mechanisms for ensuring methodological rigor: The interviews provided few solutions for ensuring methodological rigor while allowing for shared decision-making in co-creation projects. Involving citizens as quality ambassadors to guide their peers and control for scientific rigor was however suggested as a potential solution. One respondent (B16) showed that highly committed citizens identified ambiguous task designs which could have undermined the validity of data collected by peer citizens:

"We had an advisory board made up entirely of citizen scientists and they were really helpful in revising [...] our field protocol because they were the ones in the field, knowing what works and what doesn't and also knowing even just the norms. [...]" (B16)

There is no clear evidence that any platform has mechanisms in place that truly support methodological rigor and co-decision making of citizens. For example, one hosting platform involved citizens in reviewing and validating the task design of CS projects proposed by researchers. However, as those citizens were part of a "beta testing community" (P4), it is not known to which extent their contribution is directed towards scientific knowledge production. In contrast, a platform user (P6) believed that engagement platforms could ensure methodological rigor while engaging citizens in the verification of peer contributions. However, it seems that the verification process is voluntary and its' effectiveness needs to be validated.

“I do see places where [the engagement platform] can help as far as validity of data; [...] if people are actually collecting data and putting it into this platform [...] other people within the group can see it and you can have conversations about the data and say, ‘This doesn’t quite look right, can you tell me where that data point came from’” (P6, engagement platform)

Lastly, the remaining platforms do not provide suitable mechanisms to ensure high methodological rigor in co-creation. According to P3, labor platforms incorporate high quality standards, however, those solutions are mostly applied for commercial purposes such as “data annotation”. Respondents of crowdsourcing and service platforms (e.g. P8, P9) indicated that both providers did not offer suitable solutions to validate scientific rigor in co-created project settings:

“In terms of [methodological rigor], we don’t necessarily have best practice designed or a way in the system to set that. You’d just have to define it yourself.” (P9, crowdsourcing platform)

“We don't correct [inaccurate data] entries” (P8; service platform)

Establish and share best practices: None of the investigated listing platforms and respondents offered concrete mechanisms to ensure methodological rigor in co-creation. While three project listing platforms foster knowledge exchange and/or provide advice on methodological concerns in CS (P1, P2, P9), they did not elaborate mechanisms for co-creation.

“There's no specific things we can offer except to again to exchange between the different projects.” (P2, project listing platform)

Overall, several respondents highlighted that ensuring methodological rigor while engaging citizens in co-creation, requires opportunities to exchange knowledge on best practices (e.g. B2; B5).

In summary, the barriers of will of the researcher originate from researchers’ perceptions, attitudes, beliefs and values and result in a researcher not *intending* to pursue co-creation, for example due to a fear of uncertainty and change. Solutions to change these perceptions include better promotion of the benefits and best practices needed to increase the scientific rigor so that co-creation becomes more accepted in the scientific community.

6.3 Barriers of ability of researchers

Barrier of ability (R4): Researchers’ lack of knowledge and skills

An actual or supposed lack of knowledge or skills of researchers can also present a barrier to transitioning to co-creation. This can include not knowing a) that co-creation is an option to be pursued, or b) how to conduct such a science project.

Lack of knowledge of co-creation: One researcher described that at the time of the project launch, she did not consider a co-created project because she was not aware of it; it was not typical in her field (B8, A project). She said that if she relaunched the project, she would reevaluate the engagement.

> *"When I first considered [it], no I did not think about how the citizens could contribute to those multiple aspects in the research cycle. It was about four years ago when I first started with the idea for the [project] and it's only in the past three or four years now, that the frameworks for CS have opened to include [...] citizens [contributing] to multiple aspects of the research cycle."* (B8, A project)

Lack of knowledge on conducting co-creation projects: Five interviewees stated that a lack of best practices was a hindrance. To illustrate, one interviewee knew about co-creation but was not able to apply this knowledge to her situation due to a lack of best practices. She settled with a lower form of engagement:

> *"We aim [...] to find a (..) suitable way by which a CS can be effectively implemented in research activities. Because when I started to read about CS, what I found was a lot of studies [...] but they didn't tell me how this data fit the research processes."* (B7, non-researcher, ML project)

Many other researchers who engaged citizens in several research phases indicated that the project was an experiment (B2, B3, B9, B15-P8, B17). Due to a lack of best practices, they did not know if their approach to CS would be successful:

> *"[We would have needed] some more information on best practices. It was really testing the co-creation approach in the [humanities] and therefore I wouldn't say that we failed but it was a real problem - involving citizens in all the steps."* (B2, B / aspired D project)

In contrast, none of the projects that engaged citizens in only few research phases (i.e. all A projects) complained about a lack of best practices. Thus, a lack of best practices is a hindrance to transitioning.

Insufficient skills for existing projects: Eleven researchers revealed that they had insufficient skills to initiate their projects. Only two researchers found that they had sufficient skills, particularly highlighting their advanced communication skills (B13, A project; B11, C project). At another point in the interview B13 however later stated that she hired technical staff, indicating that she did not actually have all skills herself. Several non-researchers (e.g. B1, B7, P1, P2, P4) confirmed that researchers lacked motivation, coordination, marketing and social media, communication, and legal skills. Two researchers described having challenges a) with communicating with citizens (B6, ML project), and b) with coordination, particularly task design (B17, ML project). ML tried to involve citizens (i.e. teachers) in task design but could not sufficiently ensure feasibility due to wrong estimation of skills.

Insufficient skills for co-creation projects: Expected coordination problems were a reason for researchers to not pursue higher levels of CS. Project and task design, task allocation and matching were mentioned as issues by three researchers (B8; B14-P6; B15-P8), for example:

"Things that would keep me from co-creating. [...] It's just finding the appropriate project." (B14-P6, A project)

Finally, five interviewees expected and / or experienced that co-creation projects would require acquiring new skills and capabilities that they lacked, for instance mediation, diplomacy, listening skills, and stronger communication skills:

"There would be definitely anything related to mediation. To find compromises, or to find a consensus. So, diplomacy maybe, [and] not being the expert telling others what to do, but listening (B2, B / aspired D project)

"I think for a co-creative CS project there's definitely a different set of skill set you would need rather than running an online CS project and definitely those communication skills are it" (B14-P6)

6.4 Solutions to barriers of ability of researchers

Solution (R4): Educate researchers and help to acquire new skills

Establish and share best practices: Several respondents (B2; B5; B7; B11) pointed out that guidelines and best practices on co-creation would be particularly helpful, specifically in domains in which CS is an unknown or uncommon approach.

As outlined in solution (R1), hosting and listing platforms were found to publish articles on citizen-science related subjects. This includes shared knowledge on CS best practices. For example, two out of five investigated project listing platforms published guides or white papers on CS best practices, albeit not specifically related to co-creation. An interviewee (B2), using a project listing platform reflected that educational efforts were not directed towards co-creation. Therefore, she perceived that the offered services did not cover the knowledge gap on co-creation:

"[...] co-creation is not very common on these [project listing] platforms. [...] We had to figure out everything on our own and find solutions [...]." (B2)

Foster exchange among scientists: Further interviewees asked for an exchange among the scientific community. For example, respondent B11 wished for information and networking events:

"[...] information events and campaigns would [...] be useful [...], where various successful and unsuccessful CS projects would be presented together with best practices derived from them." (B11)

In a similar vein, another respondent (B17) stated that she could help in other CS projects by giving advice based on her experience. This example shows that knowledge sharing could be a solution to the knowledge gap on co-creation.

As previously outlined in solution (R1), project listing platforms offer solutions to share and exchange knowledge. Two out of five project listing platforms were also found to provide opportunities to network among researchers. P2 highlights that onsite working groups and community meetings impart a sense of belonging and provide and informal source of best practices. On the question which platform feature is the most helpful, P2 provided the following answer:

"I think that the project initiators are in one network and can exchange with each other." (P2)

Engagement platforms also enable communication between researchers. But P6 does not believe that these platforms help researchers to acquire all the skills like communication skills necessary for co-creation. B16 created an own channel on an engagement platform to exchange and discuss themes related to CS.

"I don't think it really helps you gain [communication] skills, but what it can do is if there's [a researcher] who maybe isn't as good with face to face communications with people, they might feel more comfortable having written communication[s]" (P6, engagement platform)

"[...] we always did get really good engagement among practitioners. I mean, my reach has been among practitioners of CS not among volunteers for the most part." (B16)

Hire new team members, collaborate with partners or expand skill sets: Researchers can compensate for a lack of skills by hiring new team members, collaborating with partners, or by expanding their skill set. Indeed, due to having solutions in place, nine researchers did not find that their lack of skills presented a barrier to their respective project. Four researchers partnered with external organizations or hired new team members to assist them in science communication, outreach and/or volunteer coordination (e.g. B1; B2; B7; B9; B14-P6).

"We can hire a communication person for instance. This is not something you just do on the side." (B5, MH project)

In the case of B9, collaboration partners provided skills (e.g. recruiting), but also ensured higher credibility by reaching out to an existing crowd through their channels and provided workspaces for the project. Three interviewees (B5, B13; B15-P8) used self-learning methods to become more self-sufficient::

"There're some serious skills involved that I had to acquire along the way. [...] If I sit down and design a leaflet that takes me hours over hours [...] but still I like the challenge" (B15-P8, D project)

It is evident that for transitioning to co-creation, researchers have to enjoy learning new skills. Interviewee B9 recognized her lack of social media skills but did not seem inclined to expand them:

"I think, I don't have so many skills in social media design or social media communication. I don't like that, so I don't have the skills." (B9, MH project)

Similarly, B2 suggested that one's personality and work preferences were important factors determining if a researcher pursues a co-creation approach:

"[It needs] people who are more open to engage in dialogue with people and who love, or really love, doing science communication" (B2, B / aspired D project)

Science communication is a focal service point of all project listing providers; aiming to facilitate public outreach, citizen recruitment and retainment. For example, a common service among project listing platforms is the consolidation and distribution of project information through blog entries or project web-pages. Two out of five investigated hosting platforms offer to manage the science communication and project's promotion for the researcher. For example, one interviewed platform stakeholder (P1) states that she reviews and edits the project description to ensure that the content is understandable and sounds appealing to citizens. Two other platform stakeholders (P2, P9) advise researchers on communication and participant recruitment strategies. It is not known to which extent science communication services are offered by the other platforms. Referring to the recruitment of citizens, P9 further elaborates:

"For finding skilled participants, we can only offer to help in identifying target audiences and related channels of how to get in contact with them." (P9)

Beyond personal advice, P2 and P9 also provide the option to organize online or offline training sessions and workshops to equip researchers with skills needed to conduct CS. P2 states:

"[...] if they don't have the skill in their team, they try to get it [...] If they don't have the skill themselves [...] they can [...] develop them with the help of us or with the help of the workshops" (P2)

Listing and hosting platforms offer to complement researcher's skills. For example, all hosting platforms are technically specialized to enable researchers to create standardized or customized features for their project. Further, one hosting platform facilitates volunteer coordination (B6):

"I'm not communicating with the seventy volunteers that were reviewing our [bespoke] platform, I'm not talking to each of them. [...]. [The volunteer coordinator] is representing or giving voice to all [...] and saying 'you didn't consider this one or you didn't consider that one and so on." (B6)

In contrast, service providers can complement researcher's lack of technical abilities. They offer a technical framework on which the project can be built and customized. Instead of promoting a CS project for the researcher, service providers develop the necessary tools to enable researchers to create public outreach themselves. Accordingly, two platforms offer to develop tailored project websites, whereas another offers to set up a project blog. Interviewee B2 highlights that using a service platform reduces technical burden:

> *"[...] there was already an app, already a tool – it has a predefined structure and it was already tested"* (B2, B / aspired D project)

Lastly, respondent P3 stated that researchers can identify crowd members with specialized skills through labor platforms. However, she also emphasized that crowd members must publish the skill on the platform:

> *"[...] for some things you want to access people who have special skills or special knowledge [...] [But] because it's not like regular job for them [...] it's harder to address [such people with such special skills], it's harder to build up infrastructures to find these people."* (P3, labor platform)

As previously outlined, the respondent believes that labor platforms did not provide a suitable format for co-creation due to the platforms' commercial format. In summary, the barriers of researcher ability for example result from researchers not knowing how to complete desired co-created projects. Solutions include education through best-practices and the use of platforms where researchers can network to obtain ideas from each other.

6.5 Barriers of ability of citizens

Barriers of ability of citizens result from an actual or supposed lack of scientific and domain knowledge of citizens that discourages researchers from attempting to co-create with these citizens.

Barrier of ability (R5): Citizen's lack of knowledge and skills

A lack of scientific literacy: A lack of scientific literacy makes it difficult to transition to co-creation projects as it causes researchers to limit the type and number of tasks trusted to citizens and the decision rights they receive (see also barrier R3). Nine researchers expressed difficulties in involving citizens in the design and planning, analysis, and writing phases in which scientific literacy is strongly needed. Some researchers expressed challenges in finding skilled participants, for example B11:

> *"Particularly in the field of data analysis, where both statistical knowledge and knowledge of different analysis methods is required, it is difficult to find enough skilled participants."* (B11, C project)

Others could find participants but were later dissatisfied with the quality of the results in the empirical, analysis, and writing phase.

"I was fairly dissatisfied with the processing and coding of data, fairly dissatisfied."[19] (B17, ML project)

One researcher (B6, ML) had tried to involve citizens in the writing phase and stopped doing this after having made a bad experience in one of her previous CS projects:

"I did receive [a text] and I did invest time to improve it [...] My experience was [that] I underestimated the time that it was costing me to get it properly as I wanted to have [it]." (B6, ML project)

Four researchers emphasized that they did not agree that a lack of scientific literacy was a problem, but it was the effort and time needed to acquire scientific literacy that presented the barrier:

"You have to consider that it takes a lot of time to get these kind of skills or these skills are not only something that you learn, you have to experience them [...]. That's a problem [...]. The lack of skill is not a problem but the problem is that skills are so hard, they are not so easy to get." (B9, MH project)

In confirmation of the above, projects (e.g. B3, D project) which tried educating citizens found that they could not educate citizens sufficiently, remaining "at the surface".

A lack of domain knowledge: In certain disciplines, researchers take years to build scientific domain knowledge which is difficult for citizens to obtain. The skill barrier limits the number of research phases and decision rights awarded to citizens. While researchers in the humanities (e.g. B15-P8) and biology (e.g. B14-P6) expressed that a lack of domain knowledge did not hinder citizen engagement, researchers in technical fields (e.g. B8, physics, B7, engineering) expressed concerns. Interviewee B7 did not expand citizen involvement (particularly to the conceptual phase) due to a lack of domain knowledge of citizens:

"The conceptual phase was done by researchers (...) there are not a lot of people [who are] aware of the problems of [specific research field]" (B7, ML project)

Barrier of ability (R6): Citizens circumstances or demographics

Barriers of ability can also be caused by personal circumstances or demographic factors of citizens such as their health status or age. Eight researchers agreed that this was preventing further adoption of co-creation. Examples are provided below.

[19] This text extract was translated from German to English by the authors

Restrictions due to health status: Medical researchers who want to involve patients to incorporate their experiential knowledge can face added challenges because certain diseases can restrict an individual's ability and the tasks that he/she can be involved in:

> *"[They] have a disease that makes it hard to focus on things, to concentrate on stuff for extended periods of time. It's very individual, but that's one thing we also noticed."* (B5, MH project)

Restrictions due to age: Citizens age may restrict capabilities and the scope of involvement. The elderly sometimes do not possess technical skills to participate in online projects (B16, expert). Co-creation with young children who have not completed basic education can be difficult, especially when children are not able to read or write (B1, non-researcher, A project).

Challenges in school projects: Independent of students' age, co-creation with schools can be difficult. All interviewees (B4, A project; B6, A project; B17, ML project; B1, A project) who conducted CS with schools indicated they had to adjust the project duration and format to the school setting, and suggested that the short project duration did not allow for a co-creation project, e.g.:

> *"It is a very traditional crowdsourcing or traditional CS in that citizens are only involved in collecting and categorizing or classifying data. [...] This is because of time constraints"* (B1, A project)

The respondent further emphasized that they would have to plan a school year ahead to enable co-creation, particularly in the conceptual phase, which was not feasible in project timeframe.

6.6 Solutions to barriers of ability of citizens

Solution (R5): Educate citizens and help to acquire new skills

Educate citizens: Several researchers provided citizens with domain-specific educational material (e.g. B8), some offered workshops (e.g. B9), webinars (e.g. B3) or onsite training sessions (e.g. B17). Training citizens sufficiently, especially throughout all research phases, however, demanded extensive time investments made by researchers:

> *"[...] we try to compensate [missing skills] with some webinars, but it's clear that we can't do that in a sufficient way [...]. I think that is always the case in a CS project where you involve citizens during the whole process [...] they can't bring the same skills as professional scientists."* (B3, D project)

Interviewee B8 (A project) emphasized the importance of educational efforts in addition to framing a problem to make it less difficult (cf. coordination skills, barrier R4).

> *"[Citizens] don't have the extensive domain specific knowledge as a researcher [...]. Thus, it requires that the researcher provides the necessary educational material and initial starting questions and*

framings of the questions to enable the citizens to be part of that conversation." (B8, A project)

Partners could provide additional capacities to train or guide citizens, as the case of B1 shows. In this particular case, the researcher of the project collaborated with a partner (i.e. B1) who provided educational material for training citizens. Educational material could also facilitate co-creation, specifically in fields in which educational efforts are strongly needed.

Three out of five hosting platforms provide ways to educate citizens through training on research tasks (e.g. feedback, tutorials, guides) and the provision of domain-specific background material. However, most educational services are not far-reaching, as hosting platforms are set up to inform citizens about the project's study background or improve citizen's accuracy in specific tasks. For example, to increase citizen's skills on data annotation one platform stakeholder uses tutorials and feedback loops:

"[...] for increasing the skill of a volunteer on a task is to just to teach them exactly how to do that task with a tutorial [...]. Then we've got other things we can do including feedback [...] when our volunteer either answers correctly or incorrectly we can give them feedback immediately." (P4, hosting platform)

Further, P4 highlights that researchers occasionally falsely assume a task to be too complex for citizens. As outlined in solution (R2), proposed projects are reviewed by citizens, allowing researchers to better assess citizens' capabilities.

"[...] sometimes researchers think it's too complex, then they find that it's not, which is good. It's always good to test that hypothesis" (P4, hosting platform)

Similarly, respondents stated that researchers often perceive that citizens lack sufficient skills, while it was just a wrong project design (P2). Therefore, her project listing platforms focuses on advising researchers on the project and task structure:

"[...] we check again the design of the project which is [...] probably too much to expect from the citizens. [...] The setup of the project is probably something which hinders them to get enough participants" (P2, project listing platform)

This confirms B16's statement that a lack of citizen skill is a reflection of researcher's expectations. She believes that neither party should have an inferior resource position in true co-creation .

For project listing platforms, it was generally found that those did not offer support on citizen's education on scientific or domain-specific subjects. Listing platforms display CS projects across different fields and mostly, do not have the knowledge themselves or capacity in order to educate citizens on the respective research field.

"No, we are not experts in all those subjects of all those projects. It is impossible. We can advise researchers to do it because we know something about communication but we do not know anything about the subject of the research. They have to talk to the people" (P1, project listing platform)

Further, the analyzed sample of engagement platforms showed that citizen education is not commonly represented. Only one of five platforms, provided educational support in the form of citizen training through online courses and learning material on certain taxonomies. Further, one respondent (P6) believed that engagement platforms could also function as a channel to train citizens and share knowledge. However, the data needs to be verified.

"[...] you can do some training with people that I think would upskill them to some degree, through [used engagement platform] that would be an option." (P6)

P3 suggests that researchers could search for citizens with specialized knowledge or skills using any of the labor platforms. However, she believes that, depending on the task, it can be advisable to focus rather on established communities of practice instead of labor platforms.

"I would think that [it is] probably more useful to look into established communities of certain fields like communities that are grouped around certain topics" (P3, labor platform)

Decompose tasks: Further, two respondents (B1; B8) stated that breaking down research tasks into smaller, less complex units could help citizens to solve complex problems. This can also lower the risk of citizens feeling overwhelmed or incapable in co-creation projects.

The analysis shows that labor, hosting and crowdsourcing platforms provided mechanisms or recommendations on task formulation and decomposition. Depending on the task, labor platforms break down the actual task into micro- or sub-tasks which are then given to a crowd or individuals. However, P3 reasons that for certain tasks granularity cannot be achieved and therefore labor platforms might not be particularly useful.

"All these platforms try to break down tasks into these mini units. It's really - some tasks you cannot breakdown. The granularity of the task is crucial and the question of, if one individual is responsible for the results or if you can basically level out the mixed quality of results by giving one of the same tasks to many people and so the result of an individual doesn't matter that much." (P3)

Further, one hosting representative (P4) mentioned that researchers are advised on how they can decompose complex tasks into simple sub-tasks for citizens. The respondent elaborated that such mechanisms can support citizens in gradually developing their skills from initially simple towards more complex tasks.

"If you can break down your task into really simple steps, that helps the volunteers. We try to do that." (P4)

To ensure that citizens can meaningfully contribute to a given task, crowdsourcing platforms offer support in framing or decomposing tasks. While one stakeholder actively consults clients in task decomposition (P5), another provides support in form of shared best practices (P7). It should be noted that the solutions are embedded in a commercial context and therefore, might not directly address challenges in co-creation projects.

Solution (R6): Account for citizens' circumstances and demographics in the project design

Adjust project design and collaboration mechanisms: Researchers need to assess citizen's abilities and plan for the participant group's limitations. The sample provides two positive examples. Respondents B3 and B5 adjusted their project design to cater for patients, for example by mediating group interaction through virtual tools such as webinars to allow citizens to participate remotely, as they lacked the ability to meet onsite.

To adjust to special needs, projects must be tailored. Secondary data analysis showed that all five investigated service platforms allow researchers to customize tools and features to the specificities of their project. While two service platforms were based on open source principles, three service platforms enabled researchers to use or adjust standardized interfaces and specify new features for development. Further, hosting platforms (B15-P8; P4) provide options to customize certain features to project needs.

Crowdsourcing platforms provide the ability to customize the project design and structure to project needs as well. For example, it is shown that one provider offers the option to submit idea proposals offline if geographical network coverage does not allow for online participation.

"[...] not everybody has the internet, right? It's still a challenge [...] Some people will run regular paper based campaigns [...] We really want to try and capture as a large of a crowd as possible." (P7, crowdsourcing platform)

Collaborate with lay experts to frame tasks: Further, coordinators can bridge the needs of researchers and specific citizen groups. A best practice is provided by several respondents (B1; B4; B6; B17) who conducted their CS projects with school classes and collaborated with teachers. One non-scientist (B1) recommended task-decomposition to make tasks solvable and collaborate strongly with teachers in the design and planning phase. In the projects, teachers were able to assess the capabilities of school children more accurately and facilitated coordinating the research activities with the school authorities. Therefore, teachers were frequently perceived as core facilitators. A hosting platform (P4,B6) offered staff capacity to coordinate engagement between the research team and volunteers. As previously outlined in (R4), one hosting platform supports volunteer coordination by offering researchers a direct person to contact. Secondary data analysis further shows that, for example one crowdsourcing platform facilitates the work of project teams by allocating an internal employee as project manager.

Design the study with citizens: Finally, two respondents suggested - without having made the experience - that citizen demographics should not be a barrier to co-creation when co-creation was done “correctly”. They felt that when researchers and citizens designed the project together from front to end, they would surely find the “right” project format that would not discriminate certain citizen groups (B1, non-researcher; B16; expert). This however requires flexibility from researchers (B16, expert). Finally, the authors did not identify platform solutions that could facilitate the design of a co-created project from its initiation to completion.

In summary, barriers of ability of citizens result from an actual or supposed lack of scientific and domain knowledge of citizens that discourages researchers from attempting to co-create with them. Solutions include citizen education through platforms, by researchers breaking down problems so that solutions require less knowledge as well as considering individual citizens demographics and educational background when allocating tasks.

6.7 Barriers to engagement and team development

Team level barriers which are related to team development or formation, can hinder transitioning to co-creation. These are presented in this section.

Barrier of engagement and team development (R7a): Expected lack of engagement of citizens research driven projects

A barrier is an experienced or expected lack of citizen engagement, which occurs when citizens refuse to participate in a research project or in certain research phases when this is offered to them, or alternatively when citizens participate in a project but do this at levels that are lower than desired by researchers, or simply when researchers expect a lack of engagement.

Expected lack of engagement: An expected lack of engagement is a prominent barrier. Eight researchers expressed how they did not involve citizens in more research phases and/or decision-making because they expected citizens not to be interested. The researchers did not verify this assumption, however. The below extract illustrates this:

> *“We don't have plans to engage them in conceptualization or data analysis or writing simply because people like to participate in collecting data [...] Maybe I'm underestimating it, but I just don't feel that people would want to get involved with that kind of depth in the paper.”* (B13, A project)

Barrier of engagement and team development (R7b): Experienced lack of engagement from citizens in research driven projects

Experienced lack of engagement: Several researchers also experienced a lack of engagement. Nine interviewees said that they had trouble recruiting citizens or keeping them interested throughout the research project's duration. Researchers struggled with recruitment in all research phases. However, the problem was especially prominent in the analysis phase (five researchers described problems[20]). The least problems were experienced in the empirical phase; only two interviewees (B2, B & D project; B10, C project) described having problems. Both wanted to involve citizens who had submitted research ideas in the conceptual phase in implementing the ideas. Both only found students who did the project as part of the curriculum. In project B2, the general population were not interested in implementing the ideas due to a lack of time and because they believed that they were not capable of doing research.

Barriers due to the type and topic of research: The above results show that citizen engagement levels are not related to a particular research phase but depend on other factors. A platform stakeholder confirmed this, stating that different individuals were interested in different research tasks (P2). Upon closer investigation, the data revealed that a lack of engagement is related to the type and topic of research. Researchers pursuing basic research struggled with recruiting citizens (e.g. B2, B project; B6; ML project). They had to spend greater efforts on convincing citizens to contribute and faced increased demands for marketing and communication.

Four researchers believed that research driven (top-down) projects were not well suited for co-creation because they risk that researchers follow their research agendas while disregarding citizens interests. B2 summarizes the issue:

> *"Researchers have their research design, the problems, and the questions they want to answer. They use CS as a tool, and they don't use CS as an ends. In co-creation you would use CS as an ends; as the name suggests, you want to create something together."* (B2, B / aspiring D project)

Interviewee B2 (B / aspired D project) made this experience and expressed her regrets:

> *"We saw it in our project, we wanted to have this top-down approach to co-creation. So, we as researchers wanted to have co-creation, so that was not the right way in our case. So, I think this bottom-up initiative would be more important in co-creation than in other forms of CS"*

Diminishing interest over time: In contrast, recruitment was not a problem in projects relevant to the daily life of citizens (e.g. their health) (e.g. B3, D project, B5, MH project; B7, ML project; B9, MH project; B10, B11, C project). If problems were experienced, it was due to diminishing interest over time and not due to a lack of interest in the topic (e.g. B9, MH project; B3, D project):

[20] This number has to be viewed with caution because the analysis phase was the phase in which the most researchers tried to expand the involvement to. It could be that the experienced in the other phases would be similar if more researchers had tried engaging citizens there.

"People are interested in the beginning and they participate and then you approach them again and then they don't answer. So, this kind of consistency of engagement [is a problem]." (B9, MH project)

Team development barrier (R8): Diverging interests

Diverging interests between researchers and citizens: Researchers suggested that in co-creation, it is important that researchers and citizens form a team (e.g. B16). Diverging interests of researcher and citizen can hinder team goal alignment and citizens may become demotivated. Demotivated citizens generally leave the team, as shown in the section on engagement.

Four researchers said that they were not co-creating because they expected that finding common grounds with citizens would be difficult. B6 excluded citizens from task completion and decision making in the conceptual phase:

"I think the most difficult phase for me personally, is this conceptual phase [...]. I am skeptical that we will ever get to a common question for the project. Maybe it's just my mistrust, you know?" (B6, ML project)

The expert (B16) highlights this:

"I think aligning the expectations and the motivations is a tricky part. If they don't align or can't be mutually met even if they don't match but just to be sure they're mutually met, could be really difficult" (B16, expert)

Diverging interests between researchers and collaboration partners: It should be noted that in interdisciplinary projects (e.g. B5, B3, both in the medical field) researchers initially struggled due to a misalignment among researchers (not with citizens), and some projects (e.g. B9) that collaborated with external partners described problems due to diverging interests. Thus, diverging interests are a problem that researchers face with citizens and other parties alike.

Team development barrier (R9): A lack of mutual trust and respect

An important step to team development is to align the team after phases of conflict. Establishing mutual respect and trust is key at this point but can be challenging. Both citizens and researchers sometimes don't respect or trust each other.

Skepticism from citizens: Four researchers (B2, B4, B6, B15-P8) said that they encountered skepticism or distrust from citizens. It originated from a public misconception of CS (citizens assuming that they were being "used" by researchers) or skepticism towards science and scientists in general (deficit model). One researcher expressed that she was alarmed by public or societal prejudice and stereotyping:

"I heard [this] kind of prejudice and this was also something which, was – I can work with skepticism [...] and kind of different concepts of science, but I don't like these kind of prejudices and stereotypes about scientists and that was what really pissed me off kind of [...] (B9, MH project)

Three researchers (B2, B6, B9) also described that citizens questioned the raison d'être of basic research (B2, B6) and qualitative research methods (B9), placing a burden on team formation.

Skepticism from researchers: Researchers can also be skeptical. For example, researchers do not always value the contributions of citizens in other phases of the research process than the empirical phase (suggested by B16). Further, some researchers don't trust the quality of contributions of citizens (cf. barrier R3), limiting the number of tasks and / or decision-rights of citizens. Further, interviewees (e.g. B2, B16) pointed to a hindering "ivory tower mentality" of other researchers who believe that research should be led by scientists. An ivory tower mentality was identified in three cases (B5, B7, B8). B5 was not skeptical towards citizens but rather wanted to leverage her knowledge to provide service to citizens, in line with Wilderman (2007)'s Community Consulting Model. B8 believed that in her field, research has to be led by scientist due to a lack of domain knowledge of citizens but pointed to educational means that could help involve citizens. B7 reinforced an ivory tower mentality as a science facilitator because she used CS as tool for data collection:

"I mean, truth is, although we have very highly educated participants, I think we are doing what we do because we are good at it." (B5, MH project)

"Researchers have to do research. [...] We have to find a way in which citizens can co-create with us, providing us their experience but also letting researchers have enough time to do research." (B7, MH project)

Team development barrier (R10): Missing team spirit

To perform at high levels, CS project teams should aim at building a team spirit (B3), but this can be difficult. As mentioned before (cf. R7), two researchers (B3, B9) did not have any problems in recruitment but struggled with keeping team motivation high.

Challenges from limited face-to-face interaction: The data revealed that team formation, and especially building a team spirit, is difficult without face-to-face interaction. Researcher B3 said that while citizens were generally willing to contribute due to an interest in the research topic, it was a low team spirit, caused by the team not being able to meet in person, which impacted citizen motivation. She emphasized that the team would have needed more personal contact points in addition to interaction through digital means such as emails or instant messaging, however, was not able to do so due to circumstances of citizens:

"We [met] only quite rarely. I have the impression that this affects [...] the spirit of the whole team and not maybe the motivation, but sometimes for example I have a feeling it's more difficult to motivate the [citizens] to help in the specific tasks [...]" (B3, D project)

Team development barrier (R11): Barriers related to co-creating with a large crowd

Challenges in coordination and decision-making: Conducting a large-scale project can be a barrier to transitioning to co-creation. Similar to offline projects, small-scale projects were preferred by ten interviewees for conducting a co-creation project. Researchers expected difficulties in coordinating tasks and engaging in dialogue and decision-making with a large group of people. Interviewee B3 (D project) highlighted that she decided to limit the number of decision makers to mitigate possible challenges related to having too many decision-makers:

"We are about twenty persons and that's about it. From the first side because as I said for the process of also designing a research project and formulating the research questions, it doesn't make sense to have even more people involved." (B3, D project)

Barriers to sharing intermediate results: Further concerns were related to sharing intermediate results with a large crowd, finding a topic of interest to everyone, and a limited capacity of researchers. Interviewee B1 elaborates:

"And challenges – it [would be] a challenge to do [co-creation] on a larger scale for us since geographically the [citizens] are spread all over the country and usually there is one or two researchers involved and about thousands of [citizens]. I think one way of doing it for us is to have a smaller group of [citizens]" (B1, A project)

6.8 Solutions to Barriers of engagement and team development

<u>Solution (R7): Solution to lack of engagement</u>

Capture and retain citizens interest: The expert (B16) recommended that research projects should capture citizens' interest:

"I feel like most people who aren't scientists come to science because they need a problem solved [...]. It's such a big investment in time and energy, to do the work of a scientist - but not be on the paid side of that."

One way to do this is to pursue bottom-up projects in which the demand for the project originates from the community (B16). However, despite this advantage of bottom-up projects, researchers should be aware of potential issues. The expert (B16) suggested that communities have high expectations of researchers, e.g. that researchers should act as facilitators who follow the community's agenda. Further, interviewee B15 pointed to a motivation asymmetry due to which citizens end their engagement after fulfilling their personal goals, leaving researchers without results.

To stimulate and capture citizen interest, platforms can offer different mechanisms which are outlined below.

Collaborate with external parties to identify and recruit interested participants: Finally, collaboration with CS stakeholders can provide a solution to projects that struggle to find interested participants. Researcher B2 expressed that in retrospect, she would have changed several things about her project to make it more successful:

> *"First, it would be a good idea to involve associations [...] dealing with the topic because they are very interested in the topic (intrinsic motivation) and they have already established a network. Second, we would aim at more media coverage (in addition to social media) to make people aware of the project."* (B2, B / aspired D project)

Secondary data analysis shows that several platform types offer access to an existing crowd of interested contributors. All five of the hosting platforms contained an online community. A platform stakeholder (P4) noted that researchers chose her platform due to "the underlying thing you get as well as an existing large crowd". This is confirmed by an interviewee stating that the "broad outreach" and "international citizen base" was a decisive factor in her platform choice (B6). Broader outreach increases the chances of attracting citizens to the project and stimulating their interest in participating (e.g. P4, P6). Citizen motivation is also triggered by functions that enable citizens to filter for or subscribe to projects of interest. In this regard, all hosting platforms facilitated matching citizen's interest to displayed project topics. In addition, four hosting platforms incorporate gamification elements (e.g. leaderboards, user scores). A similar set of services was observed for three out of six crowdsourcing platforms (e.g. P5, P7) that either contain an existing crowd and/or offer to crowdsource tasks among a closed group. By setting up task descriptions that sound appealing to the broad mass of users, those users eventually self-select tasks. Additionally, P7 highlighted another used mechanism to capture citizen interest:

> *"The other thing that we say is there should be some intrinsic values to participating in a system like this, either it's like you get exposed to other interesting people."* (P7, crowdsourcing platform)

Engagement platforms also help to attract interested individuals by forming a sense of belonging and enabling exchange between multiple parties (e.g. B16, P6). Listing platforms advertise or promote the project among the public (e.g. P1, P2). For example, two project listing platforms mainly focus on communicating and promoting the project to attract and retain citizens. All project listing platforms allow searches on the project descriptions (e.g. P1, P2, P9, B2). Further, secondary data analysis shows that one listing platform also generates automatic recommendations on projects of potential interest. Secondary data shows that the labor platforms enable researchers to tap into a crowd, however P3 highlights that the motivation of citizens on such platforms can be fundamentally different. Therefore, she argues that such platforms are not a place to capture interest in CS.

Lastly, secondary data shows that service platforms do not offer services exclusive to promote CS, however, two platforms provide built-in features to increase citizen participation. For example, one interviewee, talking about another provider, uses gamification to make projects more interesting (P8). Overall, the different platform types offer varying mechanisms to capture and retain the interest of citizens.

Build a community: Community building was suggested as a mechanism to increase citizen engagement. Some researchers in the sample tapped into an existing community to find engaged citizens (B5) or establish a community by enabling interested or enthusiastic project participants to interact online (B14-P6). Some cases enabled community building through either closely collaborating with small or local teams (e.g. B3; B9), while others established a large community through long-term or virtual collaboration (e.g. B5; B14-P6). To co-create, respondents preferred to build personal relationships among a smaller or local team in an offline setting (e.g. B3; B6; B9; B14-P6).

The secondary data analysis shows that most hosting and engagement platforms set up communication channels to enable group interaction and community building. For example, all platforms have discussion forums in place. One interviewee further outlined how such forums help to foster citizen engagement:

> *"That's when we learned that actually having a discussion forum [...] can engage a volunteer to a higher level than just that first basic clicking task that they're asked to do."* (P4, hosting platform)

However, the interviewee also pointed out that, despite increased citizen engagement levels, the current discussion forum does not cater to the level of group interaction needed for co-creation. First, discussions are open to the broad mass of platform users, and second, are mostly limited in their functionality to mimic in-depth discussions. While this limitation generally applies to most investigated hosting platforms, two of them offer more sophisticated solutions in which researchers and citizens benefit from more interactive and personal communication forms through platform messaging services. Similarly, engagement platforms commonly offer to share and exchange knowledge between multiple participants (P6). This helps to create group dynamics which form a community around a common topic of interest, as P6 outlines:

> *"If you look at the [...] group [...] it's a lot of people just sharing love and joy about their [project-related topic of interest]. It has built a lovely community [...]."* (P6, engagement platform)

Nevertheless, several interviewees (e.g. B14-P6; B16) question whether online environments are well suited to mediate personal communication and others (e.g. B3, B6) and say that the distant and anonymous nature of the collaboration prevents personal relationship building (e.g. B5, B6).

Provide targeted interactions and tasks: Further, one respondent (B1) also showed that offering particularly enthusiastic citizens higher levels of responsibility can trigger higher levels of commitment. In her particular case, some citizens who functioned as coordinators between the research team and the broad mass of participants in the project, voluntarily decided to disseminate the project's results through their own channels. Similarly, two other respondents (B13; B16) point towards the need of creating a balance between volunteers that are willing to engage more deeply and those who prefer to engage only at lower levels (B13; B16). In this regard, several respondents (B2; B5; B11) highlighted that researchers should establish smaller groups of highly engaged or committed citizens that are involved from an early project stage, while engaging the broad mass in lower engagement activities.

Secondary data analysis shows that specifically crowdsourcing platforms can be suited to balance different levels of citizen engagement. Three crowdsourcing platforms provide the option of forming project groups consisting of dedicated contributors and interacting with them virtually. For example, one crowdsourcing platform offers to create a collaborative invite-only team space in which members are assigned to certain tasks and can communicate with each other (P7). Alternatively, she points out that researchers also would be able to work with a larger crowd but give permission rights to dedicated crowd members. However, as the solution is applied in the commercial field, it remains unknown to which extent this solution applies to co-creation and shared decision-making across interested citizens. Creating a project group and assigning administrative roles to members can be similarly done in engagement platforms (P6). P6 indicated that, by sharing knowledge, citizens were free to contribute to the community up to the level they preferred. However, as she ran a contributory project, it remains unclear to which extent the community could have been involved in, for example, decision-making.

Secondary data analysis also showed that solutions from hosting platforms are varied. However, there was no evidence obtained that hosting platforms could balance deeper and lower citizen engagement. Further, an interviewee (P4) explained that her platform would not suit deeper engagement levels in smaller groups, as the focus is set on achieving large-scale contributions:

> *"We're always trying to get as many people on each project as possible [...]. I could imagine if you had thousands of people in [the project] it would be impenetrable [...]. We don't really have so many people using the discussion forum compared to how many people actually do the clicking."* (P4, hosting platform)

Be transparent: Respondents frequently highlighted that continuous communication, such as updates on the current research status and feedback loops, is an important mechanism to show citizens that their efforts are well-spent (B6; B13; B14-P6; B17), increasing the likelihood that citizens remain in the project.

An analysis of the platforms' functionality showed that none of the platforms directly increased transparency but incorporated facilitating mechanisms through, for example, instant communication, content sharing or automatic status updates. For example, all hosting and listing platforms offer mechanisms to consolidate and distribute project information, primarily through blog entries, project web-pages or newsletters. Interviewee P4 emphasized the importance of services that keep citizens informed about the project's progression and results.

> *"Newslettering is super important [...] It is the way of letting people know what's happening on the platform, what's happening with their effort and getting them to actually re-engage [...]"* (P4, hosting platform)

As previously outlined, three crowdsourcing platforms enable to create a team collaboration space. One interviewee stated that this way interactions and individual contributions of team members can be made visible and transparency is facilitated (P7).

> *"The reason they choose our software is they need a place so that it's continually available for them, they need transparency and they need alignment and they need to move along more efficiently. It's actually about the efficiency around ideas not the ideas themselves."* (P7, crowdsourcing platform)

Build mutual trust and respect and team spirit: Engagement can be increased by building mutual trust and respect and by increasing team spirit which is elaborated in the next sections.

Solution (R8): Find a research topic of equal relevance to all parties & facilitate goal alignment

Find a research topic of equal relevance to all: Five researchers believed that the research topic was more relevant in co-creation than in contributory CS. To ensure engagement from all parties involved as well as goal alignment, interviewees (B16) recommended to find a research topic which is of equal interest to citizens and scientists.

Goal alignment can be achieved by establishing and driving a common mission (B7) and co-deciding on the research topic and aim to pursue (B3). Interviewee B7 provides a positive example:

> *"Everybody has the same goal. [...] At the beginning, we didn't know how people were to participate and collaborate. But at the end everybody – because they feel that this is important, open science is important and at the end, everybody is collaborating [...] because everybody has the same goal."* (B7, ML project)

As stated previously in solution to R7, hosting and listing platforms trigger citizen interest by embedding functions that enable citizens to find projects of interest. However, the available functions were not perceived as being sufficient when it comes to co-creation. For example, B16 highlights that, despite matching citizen interest with corresponding project topics, the setup of one project listing platform is rather tailored to contributory projects in which the research topic is already predefined. Alternative solutions provided by crowdsourcing platforms are found to enable group alignment. Two out of six investigated crowdsourcing platforms explicitly state that they have services to facilitate group alignment and consensus building. This was also confirmed by interviewee P7. She provided an example on how her platform supported similar cases in which a research topic was collaboratively identified:

> *"The conceptual phase I think you're right that that's something that people use [us] for all the time and I'll actually send you another case study of a research board that does that as a method of deciding what research they're going to pursue and how much money that research is going to get as well. [...] People can obviously share their initial ideas and validate them or evaluate them."* (P7, crowdsourcing platform)

Analysis failed to identify a way to find a common interest on product service and labor platforms. Engagement platforms help forming a communities of interest as pointed out by two interviewees (P6, B16). P6 believed that researchers and citizens could align on a common research topic and aims on one engagement platform. She further elaborated that voting features on the platform could facilitate this process. However, she was skeptical about the effectiveness of goal alignment through engagement platforms and would have preferred to "face to face discussions" (P6).

Solution (R9): Facilitate trust building and increase mutual respect

Facilitate trust building and increase mutual respect through various activities: Six researchers in the sample actively facilitated building trust and mutual respect. Two research teams placed a high importance on transparency and honesty, for example by making it clear that the project was experimental, and that success was unpredictable and uncertain (B10, B11, C project; B17, ML project) but acknowledged that this was very time intensive. Others showed their appreciation by offering citizens first or co-authorship (B3, D project; B13, A project), e.g.:

> *"The paper is open access and the participants are the first author of the paper. I mean it's very important to publish because it shows that the people that are engaged with the study that are collecting data, and aren't just collecting data [that is] going to a black hole"* (B13, A project)

Another paid citizens for their work (B3, D project; B9, MH project), organized team events (B17, ML project), and collaborative governance models (B5, MH project; B2, D project). For example, B5 (MH project) emphasized that it was important to listen to citizens, address their concerns and feedback. She also used respectful terms to address citizens:

"We don't like the words patients, so we call it persons with [the specific disease]." (B5, MH project)

Interestingly, the D project (B3) used a combination of many mechanisms. Further, another interviewee (B2) decided to signal her project's trustworthiness through an online platform (B2, B / aspired D project). She reports that one project listing platform reviews project proposals stringently according to certain project quality criteria and in case of approval, labels the projects as 'trustworthy'. This way, citizens are assured to contribute meaningfully instead of being exploited.

"Because our initial idea was to have this co-creation approach and it was very important that we show that we don't see people as data slaves or honeybees of research." (B2)

Conduct long-term projects: The analysis provides some evidence that trust building is easier in long-term endeavors. One researcher found that building mutual respect and trust was difficult because of the limited time frame of her study (3 years). She expressed that in retrospect, she would aim for a longer-term project:

"I think I would try to get funding for a longer period - if this would not be possible, I would try to do less and maybe focus more on details I could not know in advance in this case, as for instance the very long time people need to identify themselves with a project." (B6, ML project)

The researcher also expressed that she had been working with a few individuals on an ongoing basis and could imagine co-creating with them sometime in the future:

"There are always a few that are very interested, really very interested [...]. I can imagine that out of this relationship that is building over a longer time, there could be a co-created project. Out of this reciprocal knowledge each other, how I'm working, how they are working, what they want, what I want and there, there are ideas getting generated." (B6, ML project)

A conclusion with regards to relationship building and time can however not be drawn from the sample since B15-P8 is engaged in a long-term endeavor[21] and experienced endured skepticism from some citizens, too.

No conclusive evidence could be obtained on how platforms enable long-term trust building. Several respondents (e.g. P3, B16, P6) said that labor (P3) and engagement platforms (B16, P6) can impede trust building. P3 highlights that monetary incentives on labor platform distorts trust. She elaborates:

[21] The long-term endeavor refers to the activities as a platform provider in which B15-P8 regularly interacts with citizens

“[...] you immediately attract totally different people. It’s really a tradeoff if you get maybe better access to more skilled people, but they are motivated – it brings us to the beginning of the conversation basically, because they are then motivated for other reasons. They’re probably willing to do less work and also are not likely enthusiasts” (P9, labor platforms)

With engagement platforms, interviewees (B16, P6) expressed concerns that anonymity may encourage data misuse which leads to distrust. P6 has formal rules to protect the established online community from “hatred” and other negative influences from other platform users, and provides options to kick members out.

“I think we wanted to manage the group to some degree, to make sure that it was a friendly and collaborative place. [...] There’s these platforms where people can really spew hate and betrayal and we didn't want this to go that way.” (P6, engagement platform)

Solution (R10): Build a team spirit by enabling team and community building

In terms of team spirit, respondents (e.g. B3; B6; B5; B9; B14; B16) highlighted the need to have regular face-to-face meetings, build strong personal relationships, and develop a community.

Conduct offline projects: To build a high team spirit, respondents pointed to conducting offline rather than online projects. The majority of interviewees (9) agreed that co-creation would be easier in offline compared to online settings. Some criticized the anonymity attached to online environments (e.g. B15-P8), others the reduced possibilities for “discussion, negotiating, explaining, interpreting, defending, and changing your mind” (B9), or building a connection and team (B9, B2, B3, B16). Interviewee B2 explains:

“I think especially in co-creation you have to have this personal contact, these face-to-face meetings, or workshop [...]. Of course, you can have a very active online community as well [...] [but you need] face-to-face meetings or that you sit together and talk about things that are not really related to the project; to have this personal connection with people.” (B2, B / aspired D project)

Secondary data analysis shows that none of the six platform types enables researchers to facilitate in-person community building. Although online communication channels can foster virtual group interaction, several platform stakeholders believed that those mechanisms would not be sufficient to foster team spirit for co-creation (e.g. P4, P6). Three platforms help organize offline meetings. For example, one listing platform provides the opportunity to arrange and share online or offline events among the community (e.g. bioblitz). However, as B16 outlines, the latter platform setup is rather suited for contributory than co-created projects:

"[This platform] is not set up for co-creation, it's set up for contributory projects at the moment [...]. I mean like right now people can have an account and create a dashboard with your profile and stuff like that, but they're not connected yet, it doesn't go that step further yet." (B16)

The authors did not conduct interviews with the other two platforms. Both contain project and community building elements and therefore are labeled as hybrids. However, secondary data analysis shows that both platforms mainly facilitate citizen contributions in form of data uploads to repositories in which collected data is shared across all platform members. Additional data needs to be obtained to derive to conclusions on their support in building team spirit for co-creation.

Solution (R11): Provide infrastructures for collaboration and adjust governance forms

To facilitate forming a cohesive team with a large crowd, previously outlined mechanisms to increase citizen engagement such as community building and communication are also applicable.

Use digital tools with large crowds: For large and/or dispersed groups of citizens, respondents suggested the use of digital tools to mediate group interaction (e.g. B5; B14-P6). The use of technical platforms is effective in projects with large crowds. One researcher suggested that online mechanisms could facilitate certain steps of the research process:

"To decide on certain things like on a topic, I mean you could easily do this via an online voting. [...] To present ideas or project results; the webinar is a good forum and there of course you can invite feedback, so that's feasible" (B5, MH project)

Three of the nine researchers (B14, B4, B6) acknowledged that for projects with a large, dispersed group of people online means may be the only feasible approach for co-creation.

Data analysis shows that online platforms provide effective means to coordinate a large, distributed crowd. As previously outlined in R7a, hosting, crowdsourcing and engagement platforms support researchers in engaging with an existent, distributed crowd. Labor and service platforms also enable researchers to interact with a dispersed crowd. While labor platforms use a broad mass of (specialized) workers to outsource tasks (P3), service platforms provide technical tools and infrastructures that support coordinating contributions from dispersed team members (e.g. B1, B2, P8). For example, B1 used a service platform to design an application for data gathering in a citizen science project of national scale. She reported:

"[...] I definitely feel that having an app certainly facilitated for the students to take part in the experiment at all. The app was more or less created on the basis of our specifications. [...] They can see, there is a concrete and immediate response and sort of [receipt] on their contribution. It is very obvious that how they contributed to the research" (B1, B project)

It was found that listing platforms did not offer solutions to engage a large crowd in co-creation. One respondent (P2) stated that researchers would need to conduct trials and use the lessons learned from the approaches to gradually build up best practices.

> *"So, let's say, they started with one simple project and they gained the experience they had from their first project and to put it in the next level and to engage more deeply and profit from the results and the knowledge they gained so far from the first step of the other project. There's nothing we offer in concrete." (*P2, listing platform)

Employ new governance forms: Further, large-scale team coordination can be facilitated by governance structures that include positions such as citizen representatives or volunteer coordinators to ensure that citizens' voices are considered (B5) and to enable effective group interaction between citizens and the research team (B4).

Interviewee B2 reflecting about her two large-scale projects (B / aspired D, MH project), recommended two different CS project formats for the future:

> *"1) Involving the masses in fewer phases (with less or no decision-making by the citizens) or 2) Involving only a smaller group of citizens in all (or more) research phases, including decision making."* (B2)

Two projects (B3, D project; B5, MH project) provide positive examples for such an approach, while still enabling the pursuit of a higher form of CS. They mixed the two options recommended by B2 and included the (large) crowd in task completion in the empirical phase, with no or little decision-making rights, while including a smaller group of citizens as representatives in other process steps and in decision-making. B5 elaborates:

> *"Citizens did and continue have an active, decisive role during [the design and planning] phase. Two [citizens] were part of the strategic committee that decided over the strategy and design [...]. Also, [..] the latest [study materials were] largely designed by citizens. In both examples citizen representatives (n=2 in the first and n=25 in the second) were present at face-to-face meetings, where important decisions were made. The voice of citizens carried a lot of weight during those meetings"* (B5, MH project)

Data analysis showed that several platforms provide researchers with alternative forms of project governance in order to facilitate large-scale team coordination. For example, on service platforms technical infrastructures and tools can be adjusted towards governance forms which also enable bottom-up or co-created approaches (e.g. P8). Here, P8 outlines that the technical infrastructure of the built application allows to "give [users] as much freedom and area or space for creativity [...] as possible."

As already described in solution R4 and R6, a respondent (B6) highlighted that she received support from a volunteer coordinator of a hosting platform. In the solution R7 it was shown that crowdsourcing platforms provide team spaces to coordinate interaction between a large team (P7). She further explained that the system allowed to assign roles to team members. Those then could take over administrative functions, as she elaborates:

"There's a section where you say, who can do it and then who can see it. You could keep the entire thing open to everybody, anybody who is in that system could do that." (P7, crowdsourcing platforms)

Further, solution R7 also showed that community engagement platforms enable to assign administrative roles to members (P6). When questioned what respondent P6 would do differently when running the same project again, she replied:

"I would set up a few of the citizen scientists who are active in the group to help manage and moderate it, as it is an ongoing task, and this would help the Facebook group carry on momentum without much researcher input." (P6, engagement platform)

The authors did not identify suitable solutions for labor and listing platforms. It was previously highlighted that listing platforms do not offer concrete solutions to enable large-scale team work in CS projects (e.g. P2), while P3 believed that labor platforms incorporate governance system which go against the idea of co-creation:

"[…] the term co-creation has this emancipatory ring to it […] – and this [goes against] these extreme hierarchies and power asymmetries that you usually have on digital labor platforms." (P3; labor) market platforms)

In summary, barriers to citizen engagement and team development originate from an *actual or expected* lack of citizen engagement which result from diverging interests, a lack of mutual trust and respect, and from co-creating with a large crowd. Solutions include ensuring that citizens interest is captured and maintained, by building teams that make project participation socially rewarding, by building trusting and respectful relationships.

6.9 Bureaucratic and administrative barriers

Researchers experience bureaucratic and administrative barriers which hinder co-creation. To overcome those barriers, respondents expressed a need to reduce the time spent on non-research related tasks, to obtain funding suited for co-creation activities and to ensure compliance with legal and ethical policies and laws.

Bureaucratic and administrative barrier (R12): Researchers' limited capacity (time)

Limited time capacity: The limited time capacity of researchers presents a barrier to transitioning to co-creation. Ten interviewees found their projects to be very time consuming. The researchers without time intensiveness issues were conducting lower forms of CS (A and ML projects).

Great efforts spent on non-research related tasks: Among the eleven, several researchers expressed that they spent a lot of time on non-research related matters, e.g. project preparation, marketing and communication or convincing others about the use and value of CS. The need for convincing others seemed to increase in disciplines in which CS was not accepted among the scientific community (e.g. humanities) and in topics of low interest to the general public. One researcher (B15-P8) had underestimated the time she would spend on non-research related tasks, revealing that she sometimes felt overwhelmed because she was alone:

> *"It takes a lot of my time and I would like to do other things than moderating content for example, or posing some social media outreach thingy to acquire new participants. Sometimes I would like to give it to somebody else [...] but I don't find that person, right?"* (B15-P8, D project)

Platform stakeholders (e.g. P2, P4) confirmed that CS was very time intensive and that researchers often underestimated the effort that went into a successful project.

Nine interviewees agreed that co-creation projects required more time than other forms of CS and that a limited capacity or time of researchers presents a barrier to co-creation:

> *"[A barrier to co-creation is] time. Time and effort. As researchers usually don't have so much time to do co-creation. Co-creation takes a lot of time, CS takes a lot of time, but I think co-creation is the most time intensive approach in CS."* (B2, B / aspired D project)

Three of the nine (B6, ML project; B13, A project; B14-P6, A project) said that this was one of the reasons why they did not involve citizens in more tasks, to illustrate:

> *"We haven't done that yet because I didn't really want to – I mean it's enough work just doing this one to tell you the truth. No, I don't see that kind of interaction happening in this study for the foreseeable future."* (B13, A project)

Seniority and time: Inconclusive evidence was found about the relationship of researcher seniority and time. A non-researcher (B7, ML project) stated that she believed that more junior researchers were more willing to work with citizens, but they had less allocated time. In contrast, B16 indicated that she had less time for CS activities since becoming faculty, and B15-P8 questioned if she would be able to continue her project after getting promoted. Further evidence should be sought.

Solution (R12): Help researchers to reduce their time burden on non-research related tasks

Solutions are presented that help reduce the time for project administration and coordination.

Divide tasks among team members: Two interviewees (B13, B4) indicated that individuals' workload could be reduced by splitting tasks within larger project teams. For instance, one respondent (B4) suggested recruitment efforts could be reduced by establishing a self-driven community that recruits other participants. However, as B13 did not see the need for co-creation, her interest was restricted to the recruitment of citizens needed for data collection.

Distribute tasks to partner organizations: Distributing administrative tasks to a crowd (i.e. crowdsourcing) or outsourcing non-research related work to individuals or partner organization was a mechanism used in a number of cases (e.g. B1; B4; B7; B9). It should be noted that cases B1 and B4 used the same partner organization to coordinate and facilitate the CS project, with B1 acting as a partner in both cases.

All the platforms types offer services to help save researchers' time as revealed by secondary data analysis. Hosting, listing, engagement and crowdsourcing platforms support researchers in coordinating with volunteers. Additionally, hosting, labor and crowdsourcing platforms facilitate the matching of tasks to the appropriately skilled citizens Hosting and crowdsourcing platforms facilitate project management. Additionally, project listing and crowdsourcing platforms help to manage communication and lastly, service providers support researchers through the technical development.

Bureaucratic and administrative barrier (R13): Lack of sufficient, long-term, and flexible funding

Lack of funding from funding bodies are a barrier to transitioning to co-creation as agreed by thirteen interviewees[22] (thereof three non-researchers, B1, B7, P9). Based on the data, the issues with regards to funding can be divided into four sub-problems which are described below.

Inflexible traditional funding schemes: First, traditional academic funding schemes are not aligned with the nature of CS, and particularly co-creation in that they are inflexible and focused on producing scientific results rather than societal value. To illustrate, B8 who was funded by a science foundation, had trouble justifying technical developments:

> *"There's a focus on the [..] domain specific science result, rather than the CS result. [...] You have to prioritize, you're getting the finances for the project to reach a certain target and if that isn't co-creation CS [...] it's hard to justify spending [...] on [a user] interface."* (B8, A project)

B9 highlighted that CS projects required more flexibility than regular science projects:

[22] Interviewee B4 established a low-cost project and did not need much money and therefore did not complain. B7 and B10 did not provide an opinion as it did not come up in the conversation.

"I think this very important thing to be flexible with the money because during the process, you always need to adapt to a process. It's not a usual project." (B9)

Insufficient funding schemes for CS: Second, there are few CS funding schemes, and especially co-creation projects, which makes it difficult for researchers to acquire funding. Two researchers pointed to the rarity of CS funding schemes:

"There was this call [and] [...] it was very open, that's very rare, these kinds of calls. [...] We were lucky [to be selected]" (B9, MH project)

Interviewee B2 highlighted that the problem increased for co-creation due to perceptions of funding institutions:

"The main barrier to co-creation is that funding bodies [...] usually see CS as crowdsourcing, as saving money, and cutting budget of universities." (B2, B / aspired D project)

Too low funding amounts and too short funding durations: Third, if CS projects do get funded, the funding amount is often too low or the duration too short for pursuing a co-creation project. The statement below provides evidence for too short funding durations:

"We were happy about [receiving funding], but they limited the time a lot [...] We only had two years [...] for the project which is very short. [...] which was kind of challenging" (B9, MH project)

Five researchers, three of which funded by funding agencies, shared that they (B3, D project; B17, ML project) or someone they knew (B2) were doing unpaid work for the project, which provides evidence for too low funding amounts:

"It all runs down to money. [...] It was definitely too low" (B2, B / aspired D project)

"I'm [not] paid [...] to do this extra work. It's also at a kind of border in my own leisure times and it's difficult to run the project within the normal frames. This is certainly a barrier." (B3, D project)

B2 emphasized that "you have to really be very ambitious to do CS", and willing to work in your free time. One researcher's case provides support for the claim. She pursued CS because of a call from a funding agency (rather than a passion for CS) and decided to discontinue her CS efforts afterwards due to low funding amounts:

"I would not be able to do it with such limited funding again - much of my time was unpaid." (B17, ML project)

Misaligned structure (timing) of funding: Fourth, the structure (especially timing) of funding applications makes it difficult to involve citizens in the early phases of the research process, especially the conceptual phase. Interviewee B6 does not involve citizens in the conceptual phase anymore for this reason:

> *"I find it very difficult to involve citizens in [the conceptual] phase because they might be [...] disappointed at the end when the grant is not funded. I had this experience [...] at the beginning, ten years ago something like that. It is not easy to explain that you can have bad luck or bad reviewer and you don't get the money and you cannot do what you plan to do."* (B6, ML project)

Seniority and funding: Weak evidence was found for a relationship between seniority and funding. Two researchers (B2, B6) suggested that researchers with a low seniority (e.g. being PhD student) experienced greater difficulties in receiving funding because they had lower credibility and were dependent on traditional, inflexible funding schemes.

Possibly insufficient support and country-specific differences: No clear conclusions could be drawn regarding a possible lack of political or governmental support, while the general tendency was discontent. One interviewee indicated that governments generally do not sufficiently support science (P4). Others indicated that governments, besides in Germany and in Austria, were not interested in CS (B15-P8; P2), and another[23] who had been funded by a ministry expressed a feeling of neglect because the ministry showed little interest in her project thereafter. This feeling was however not shared by others funded by the same body. Finally, interviewee B2 expressed that "funding bodies, universities, decisionmakers, policymakers, usually see CS as crowdsourcing, as saving money" which she perceived as a barrier.

6.10 Solutions for bureaucratic and administrative barriers

Solution (R13): Adjust the funding system or provide alternative funding sources

Increase CS funding schemes and their flexibility: Several respondents (B2; B3; B9) reported that funding schemes for CS are emerging in the European region but it is still difficult to obtain sufficient financial support. Many researchers (e.g. B2) expressed a need for creating funding schemes that account for the specificities of (co-created) CS projects, and / or changing traditional funding schemes. For example, B3 asked for more flexible funding structures:

> *"[...] I think this [is a] very important thing to be flexible with the money because [...] you always need to adapt to a process. It's not a usual project where you have your research question, your methods, your results, your analysis and the publishing. You need to be really flexible. You need to adapt the process all the time"* (B3)

[23] The source number is not revealed for confidentiality reasons

Greater flexibility would also allow researchers to obtain funding prior to determining the research topic and design, as in the case of B2 and B3 who received grants from governmental funding bodies.

Facilitation of change through partnerships and network: This would promote the development of more flexible, long-term and sufficient funding schemes for CS which could help change the science incentive system and facilitate a change in the financial landscape.

None of the six platform types demonstrates the ability to change the funding landscape. However, in solution (R1), hosting and listing platforms aim to promote CS and thereby indirectly influence the funding system. Hosting platforms showcase the value and impact of CS through publishing CS-related articles whereas listing platforms engage in lobby work such as establishing CS communities among researchers and cooperation with different institutional stakeholders.

Another aspiring platform, which was not initially included in the authors' platform typology and therefore was labeled as 'Others', was found to provide several mechanisms that could initiate a change on a meta level. It aims to "[create] a central platform for sharing knowledge, initiating action and supporting mutual learning". This includes the coordination of CS activities across projects and engagement with various stakeholders in a consortium, "including universities, non-governmental organisations, local authorities, community service organisations and museums."

Use alternative funding sources: Other funding opportunities could also solve the issue of inflexible funding. Self-sustained funding through a proprietary foundation (B13), or funding through the researcher's institution (B15-P8) provide higher flexibility than traditional funding schemes. The two respondents (B13; B15-P8) highlighted that, by surpassing external funding, they experienced higher levels of flexibility and independence:

> *"One of the most beautiful aspects of this project for me is that we don't have a deadline that we need to match. We don't have specific expectations as for what this project has to produce, there's no external funding involved."* (B15-P8)

While alternative funding sources could provide money, researchers should be aware that there are still challenges involved. B13 for example expressed that she spent much time on fundraising.

With regards to platform solutions, data indicated that no solutions from the six platform type exist. However, several platform stakeholders pointed out that they provide their (basic) solutions for free in order to reduce the financial burden on researchers (e.g. P1, P2; P4, P8, P9). For example, P8 stated:

> *"I can develop this kind of platform and give it [to researchers for free] who don't have the possibility to do something like that and maybe they can profit from it because they don't have sufficient funding."* (P8)

Bureaucratic and administrative barrier (R15): Legal and ethical barriers

Researchers were asked about governmental policies, regulations, and laws that they found to be a barrier to transitioning to co-creation projects. None of the interviewees indicated that any such issues had been the reason for them not pursuing a co-creation project, but several pointed to laws and regulations that made (co-created) CS more difficult.

Data protection regulations: The European Union's data protection regulation was alluded to by ten interviewees, including B2 who found that it made co-creation difficult.

> *"There are [...] governmental regulations that make it very difficult; for example, the general data protection regulation is really hard if you want to do co-creation and you need to know your citizens and you need to do all these things required [...]. That's definitely hard"* (B2, B / aspired D project)

Similarly, co-creation in online environments is difficult because researchers may struggle to balance compliance (e.g. through anonymization) and personalization (e.g. B2; B8; B15-P8):

> *"One of the biggest issues that researchers are now faced is data protection. [...] it is a huge concern when dealing with any type of data from computational or game-based CS games. [...] That can create more obstacles in facilitating the co-creative experience."* (B8, A project)

However, some interviewees did not find the laws and regulations worrisome. Interviewee B10 suggested that data security and privacy were issues that any research project faced, and others described it as something that "you [just] need to work with or to work around." (B5, MH project)

Impact of the geographic location: The issue also seemed to be related to the geographic location of the researcher, as a researcher located in the United States[24] disagreed that ensuring data protection and privacy presented an issue.

Issues related to handling human data: Another concern was related to dealing with human data and subjects in the empirical and analysis phase. Researchers in the medical field raised concerns about ethics (e.g. B5) that were also alluded to by others (e.g. B7).

> *"We have to apply for ethics approval because we are dealing with human data, human subjects. I mean, that's already like a certain framework that we need to adhere to."* (B5, MH project)

Solution (R14): Help comply with legal and ethical policies and laws

[24] The source number is not revealed for confidentiality reasons

Seek participant consent and/or do not collect personal data: The conversations provided solutions to complying with data privacy and protection. For example, one respondent (B15-P8) avoids legal issues by collecting little to no personal data of citizens. Another respondent (B8) used consent forms.

Out of the analyzed secondary data sample, it was identified that three out of six platform types have mechanisms in place which ensure the project's legal compliance. For three engagement platforms, two service platforms and all project listing platforms data on legal project mechanisms could not be obtained or was questioned. In case of engagement platforms, several interviewees (e.g. B16, P6) voiced concerns on data protection. B16 voiced concerns as a general issue on online platforms:

> *"I'm more recently discouraged just by all the fake conversations on social media , [driven by bots] and trolls. It's so abused right now it's hard to imagine a safe space even within data CS platform thing, a safe space for having legitimate things, virtually."* (B16, expert)

Further, it was stated that conducting projects on labor platforms, despite legal compliance on data regulations, could result in ethical conflicts due to exploitation or disqualification of workers (P3).

Interviewees generally confirmed the secondary data results. Hosting and crowdsourcing platforms ensured data anonymity (e.g. P4, P12) and secure infrastructures (e.g. P5, P7). Additionally, three service platforms show compliance to data regulations through set privacy policies. Interviewee B2 highlights that using a service platform reduced legal burden:

> *"[...] it already had all these data security and personal data protection things figured out. So, we could really benefit from them."* (B2)

Lastly, project listing platforms were found to focus on legal advice and distribution of best practices instead of the provision of built-in legal mechanisms for each project. Legal support is discussed in greater detail below.

Seek legal support: B5 recommended seeking legal support to overcome legal barriers:

> *"Data security and data privacy is currently in focus (of the public). Accordingly, lawyers must be partially involved in such projects [...] . However, this approach is now standard in many projects where personal data is retrieved (i.e. also non- CS projects).*" (B10, C project)

One interviewee (P9) pointed out that her project listing platforms provides project-related advice on legal concerns. This could alleviate legal and ethical barriers. Similarly, to previously outlined mechanisms, best practices could also provide help and guidance.

As previously mentioned, two interviewees (P2, P9) stated that their project listing platforms provide legal guidance for project initiators. Both stakeholders address legal compliance in CS through different mechanisms, as shown below:

> *"This is something we're currently working it and probably takes a bit of time to give the most of the questions people have in a legal area which is also touching a lot of data security and how to [...] save the data. We're currently working on at least a guideline."* (P2, project listing platform)

> *"For this we have our working group on legal aspects in CS projects."* (P9, project listing platform)

While legal and ethical barriers do not present a great hindrance, platforms offer solutions.

Bureaucratic and administrative barrier (R15): Organizational barriers

No barrier - Satisfaction with affiliate organization: Organizational level barriers from the research institution that researchers are affiliated with were not found to be a strong barrier to transitioning to co-creation in the sample of this thesis. When the interviewees were asked if they had faced or if they expected to face problems resulting from their research institute, none of the interviewees felt hindered. On the contrary, most expressed content. Many highlighted that their organizations' mission was aligned with CS (e.g. B2, B6, B16), that they had received sufficient support from university or institute leadership (e.g. B5) and have not been criticized by colleagues (e.g. B3, B5, B17). Since most projects had received external funding, a lack of funding from the affiliate organization was not perceived as a barrier (e.g. B9, B17). One researcher (B2) even received additional funding from her institute as her external funding did not suffice. One researcher, affiliated with a private, non-profit research institute felt that her project was particularly aligned with the institute's goals:

> *"[My colleagues] appreciate that. [..] It fits in the whole portfolio of the institute. [...] I didn't have to fight any devils"* (B2, D project)

Also, researchers affiliated with universities felt supported. When asked about potential constraints on the organizational level interviewee B6 responded:

> *"No, I would say not on the organizational level. The university (...) is standing behind [me]."* (B6, ML project)

Remote geographic location and insufficient support from research facilitators: During the interviews, some organizational limitations still came to the surface. One researcher expressed that she could not easily meet with citizens in person due to her university's remote location (B4, A project). Others (B15-P8, B4) expressed that they would have needed more support from research facilitators, e.g. the communications department:

"There the communication people [at the university], they are hidden somewhere in a corner of the building, so it's harder to get to them. I felt that I could have had more help from them." (B4, A project)

A science facilitator (B7) confirmed that university support offices were often bureaucratic and did not provide researchers with useful support:

"We have offices to support researchers, but what they do is only [to] provide assessment [...] in the legal point of view. [...] They can provide you some help if you're preparing a [grant] proposal. [...] But this is an office that is very bureaucratic. I mean, it is not a real support. What we did here in my institute, in my department, is to support the researcher hands-on." (B7, ML project)

Other researchers (B5, B15-P8), while generally pleased with the support they had received pointed to IT-related issues:

"We're very IT heavy so if we had some organizational issue, it was more along those lines; that we needed to see how we could get all the resources that we needed" (B5, MH project)

Limited decision-making: Three interviewees also indicated that their technology choice was restricted by the organization. B15-P8 for example was compelled to develop inhouse technology, B2's software choice was restricted by an existing contract by the university, and a colleague of B4 was not allowed to use certain instant messaging and video call tools.

Finally, five interviewees could imagine that other researchers faced organizational barriers. A platform stakeholder (P2) confirmed with an example:

"One person [..], she builds up a CS project and, in her institution, [...] she [had to fight against headwinds]. a lot of trouble in the administration and in the other parts because everybody was like, 'Oh no, you're doing CS! Are you sure you want to do it with citizens?' People were probably a little bit not so open-minded in her institution; depends also of the institution." (P2)

Overall, the interviewees did not feel particularly hindered. However, research institutions could still be a barrier to co-creation, and further evidence should be sought.

Solution (R15): Overcome organizational barriers

Reduce bureaucratic work: Respondents stated the need to reduce bureaucratic efforts such as "paperwork" (B7) as well as greater support in non-research related tasks, specifically concerning science communication and technical infrastructure (e.g. B2; B4; B5; B7; B15-P8).

Another solution to cope with the circumstances is to rely less on the organization. Due to long processing times to complete tasks given to the research support department, B15-P8 decided to complete tasks on her own:

"[The support staff] really want to be helpful but they can't because they have twenty-three other projects on their desk. That's the point where you decide to do things on your own because of course I could have waited two months for a poster but if I can do it in one day [...]." (B15-P8)

Collaborate with external partners to reduce inefficiencies: External partners and facilitators could also be beneficial to reduce inefficiencies, especially technical ones. As B15-P8 further outlines:

"If speed would have been a consideration [we] would have simply used another platform to make this happen pretty quickly because this entire development process, took about one and a half years [...]."

In a similar vein, B2 stated that, in future, she would try to cooperate with associations for citizen recruitment:

"We hope to start with associations with existing structures that we can use and who are already interested in this topic. And from there on we could use them as multipliers to engage more people." (B2)

Establish regional, national, or international support offices: B7 suggested that national or regional competence centers specialized on open science could be established to support researchers.

"[...] if you create national offices or well, national or regional or at the university level, [...] devoted to open science in general just to support researchers of course I will say that the initiatives will grow for sure" (B7)

In summary, bureaucratic and administrative barriers are caused by constraints that force researchers to deal with issues like obtaining their organizations' support, obtaining funding, as well as legal and ethical concerns. Solutions include e.g. using platform tools and internal organizational admin staff to help with non-research tasks. Some platforms offer assistance with tasks like project management. Platforms and organizations also help to adhere to laws and data privacy rules.

7. Discussion

This chapter is devoted to discussing and interpreting the results of the research question in light of the existing knowledge on barriers and platform-based solutions to transition to co-creation, as well as devising managerial and theoretical implications (section 7.9). It concludes by pointing to limitations and suggesting avenues for future research (section 7.11).

This thesis set out to answer the question "What are the barriers to transitioning to co-creation and how can online platforms help overcome these barriers?" To answer this question, the authors first critically reflect upon the findings on barriers to transitioning to co-creation. This is followed by a discussion of platform types which provide solutions to overcome the outlined barriers.

7.1 Barriers to transitioning to co-creation

Based on the findings, this study proposes a framework of sixteen barriers and their respective solutions. Each barrier consists of multiple interrelated factors at different levels (e.g. individual level, or group level). Some factors are derived from the literature and confirmed through the empirical study, and others derived from the empirical study alone. For co-creation to become mainstream and successfully conducted, the barriers would have to be overcome. The authors identified five types of barriers: Barriers of (1) will and (2) ability of the researcher, and (3) barriers of ability of the citizen, (4) barriers to citizen engagement and team development, and (5) bureaucratic and administrative barriers.

Barriers of will of the researcher originate from researchers' perceptions, attitudes, beliefs and values and result in a researcher not *intending* to pursue co-creation, for example due to a fear of uncertainty and change. Barriers of researcher ability for example result from researchers not knowing how to complete desired co-created projects. Barriers of ability of citizens result from an actual or supposed lack of scientific and domain knowledge of citizens that discourages researchers from attempting to co-create with these citizens. Barriers to citizen engagement and team development originates from an *actual or expected* lack of citizen engagement which result from diverging interests, a lack of mutual trust and respect, and from co-creating with a large crowd. These barriers hinder CS teams to form, norm, and perform (Tuckman, 1965). Bureaucratic and administrative barriers are caused by constraints that force researchers to deal with issues like obtaining their organizations' support, obtaining funding, as well as legal and ethical concerns.

These barriers can cause researchers not to pursue co-creation even if they are willing and able to co-create. The aforementioned barriers have different effects on transitioning to co-creation, some hinder transitioning to a broader task involvement, whereas some hinder transitioning to shared decision-making, and others both (cf. table 11).

	Impacts any phase	Impacts certain phases
Limited task completion and shared decision-making	R1, R7a, R9, R15	R2, R3, R5, R8
Only task completion not expanded	R4, R6, R7b, R10, R12, R13	R14
Only decision-making not shared	R11	n/a

Table 12: Effect of barriers on transitioning to co-creation

Task completion and shared decision-making in any phase: Some barriers impact task completion and shared decision-making in *any* phase, for example researchers' perceptions, attitudes, and beliefs (R1). These are problematic when researchers a) *perceive* CS as a tool to facilitate scientific goal achievement, without following social motives; social motives are particularly important for co-creation because co-creation provides added benefits such as democratization of science (cf. chapter 3). It is also a barrier when researchers *perceive* co-creation as not being useful and / or not applicable, or when researchers have a negative attitude towards uncertainty and change. Researchers who want to maintain control, do not pursue higher forms of CS in which uncertainty typically increases. These results confirm and extend the existing literature. It is known that higher forms of CS promise added benefits such as the democratization of science (cf. section 3.5), and this thesis shows that achieving these benefits is a key motivating factor for pursuing co-creation. Reluctance to change and uncertainty, and giving up control are known barriers to CS (McKinley, Briggs et al., 2012), and this thesis shows that they are an even more pronounced barrier to co-created CS.

Further, there are barriers to engagement and team development (R7a). Commonly researchers expect citizens not to be interested in pursuing certain tasks (e.g. analysis, writing) or taking decisions (e.g. daily decisions), which is why they do not offer it to them. These findings provide evidence for that claim that researchers presume a level of interest of citizens, which has been suggested by Hecker, Bonney et al. (2018). In difference to the scholars who argued that researchers presumed too *high* of an interest from citizens , this thesis shows that researchers also presume *low* levels of interest.

Similarly, a lack of mutual respect and trust hampers task involvement and shared decision-making in any phase (R9), e.g. because citizens do not get involved due to skepticism of science, or because researchers do not value citizen contributions in research phases, e.g. due to an ivory tower mentality. This is especially problematic in short-term projects in which there is insufficient time to build trust and respect. The findings are in line with the literature which described certain perceptions of researchers as a barrier (e.g. Hecker, Bonney et al., 2018; Riesch & Potter, 2014). They add to the literature by confirming the author's hypothesis made in the literature that trust building is particularly important in co-created projects, as researchers and citizens must equally rely on each other, and by showing the importance of setting up long-term projects.

Finally, while the researchers in the sample did not feel that their affiliate organization (R15) was a barrier, there is some evidence that organizations could be a barrier. They sometimes provide insufficient resources and technical infrastructures (especially for large-scale projects), restrict decision-making (e.g. technology choice), or the mission is not aligned with CS / co-creation. This confirms existing literature that presented organizations as possible hindrances (e.g. Dick, 2017) and supports the hypothesis of the authors that technological barriers are especially problematic for large-scale co-creation projects. However, it also shows that organizational barriers are not the main cause for researchers not to pursue co-creation.

Task completion in any phase: Several types of barriers cause researchers not to expand task involvement to more research phases. A lack of researcher-initiated co-creation best practices (R4) - for projects with task involvement in several phases - caused researchers to “experiment” with project designs or, when reluctant to experiment, choose a lower, more certain type of engagement. Further, insufficient skills for co-creation (R4) or knowledge of co-creation applicability can cause researchers not to expand task involvement, when combined with an unwillingness to expand and / or compensate for them. These findings are in line with literature that states that CS projects require certain skills that scientists do not naturally possess (e.g. Buytaert et al. 2014; Powell & Colins, 2008). They extend the literature by showing that co-created CS projects require a different and / or stronger skill.

The analysis also provides evidence that certain circumstances and demographics (R6) restrict an individual's ability and the tasks that the individual can be involved in. An individual's health status, age (young and old), and affiliation with a school (e.g. due to the structure of the school year restricting the scope of engagement), can induce challenges. These findings confirm the existing literature, showing that factors such as old age and poor health conditions can present barriers to involving citizens in research (Pope, 2005, Williamson et al., 2016). It adds to the literature by providing new examples of characteristics that can provide a hindrance (i.e. young age, school project)

A lack of engagement from citizens was a barrier commonly experienced by researchers across all project types (R7b). The results show that task involvement cannot easily be expanded when the research topic or project type do not capture citizen interest (e.g. basic research projects). However, also projects that are perceived as interesting by citizens initially (e.g. a D project) sometimes struggle with diminishing interest over time, causing them not to find participants for some tasks. This can be attributed to challenges of building a team spirit, which is particularly difficult without face-to-face interaction (R10). This indicates that not all projects are suited for co-creation, and that co-created science projects will only be successful for topics which can sustain the interest and motivation of a core group of citizens. These results are in line with literature that finds that not all topics are feasible for CS (McKinley et al., 2017). This thesis adds a new perspective to the reasons why some are not feasible by showing that citizen interest in a topic is very important, in addition to for example the complexity of a problem, which previous research has suggested (McKinley et al., 2017).

In addition, a limited time capacity (R12) is a strong barrier which influences researchers not to expand task involvement. Most researchers found their projects to be very time consuming and agreed that co-creation required even more time, which is not always readily available. Especially time spent on non-research related tasks create this problem. These findings are in accordance with the literature which suggests that co-creation is a time intensive endeavor (e.g. Dick, 2017). They also provide new evidence that shows that researchers are discouraged to co-create because they expect an even higher level of time commitment.

The strongest barrier, to which all respondents agreed, is a lack of sufficient, flexible, and long-term funding (R13). Respondents described traditional funding schemes as unsuitable for co-creation, complained about insufficient funding schemes for CS, low funding amounts, and too short funding durations, which caused some researchers to discontinue their CS activities. Also, a lack of flexible funding and an unsuitable timing of funding applications makes task involvement in the early phases of the research process difficult. Funding agencies usually ask for the research concept and design to be handed in with the application, so that citizens are commonly not included in the conceptual and design and planning phases. These results are also mentioned in the literature which has pointed to challenges related to inflexible funding schemes (Hecker, Bonney et al., 2018). They add to the understanding of the problem by showing that few funding schemes, too low funding amounts and the timing of the application also hinder the pursuit of co-creation.

Shared decision-making in any phase: Barriers related to co-creating with a large crowd (R11) result in issues related to (only) shared decision-making in *any* phase. Because researchers expect difficulties in coordinating tasks, and engaging in dialogue and decision-making with a large group of people, they limit the number of decision-makers. These findings extend the existing theory. While coordination problems in task design, allocation and matching are known problems in CS (Franzoni & Sauermann, 2014), problems related to decision-making with large crowds have not been identified so far in the CS literature.

Task completion and shared decision-making in c*ertain phases:* Some of the barriers impact task involvement *and* shared decision-making in *certain* research phases. Barrier (R2) causes researchers to exclude citizens from the conceptual and writing phase. The root cause of the problem is the science system which was described as a barrier by almost all researchers. However, many researchers still pursued higher forms of CS, and particularly co-creation. It became evident that the system by itself is not a barrier. Instead, it only presents a barrier in combination with an individual's' career opportunities / aspirations and a desire to publish in peer reviewed journals (R2). These results are in line with the literature which presents the science system as an obstacle (Hecker, Bonney et al., 2018). However, it also shows the importance of the microfoundations of co-creation which can have a decisive effect.

The results (R5) indicate that skill barriers of citizens are especially problematic when the project duration is short or when researchers have limited personal time available, because the limited time prevents sufficient citizen education. Because citizens have insufficient scientific literacy (R5), it is difficult - for researchers wanting to adhere to good scientific practice (R3) - to involve citizens in task completion and decision-making in the design and planning phase, and in decision-making in the design and planning, empirical, analysis, and writing phases. Researchers across *all* project types feared that citizen involvement in these scientific tasks may reduce the scientific rigor and thereby prevent the research from being published. Citizens were assigned the more academic tasks mainly only when the projects were considered experimental. The results indicate that adherence to good scientific practice is a prominent and difficult to overcome barrier unless citizens scientific literacy (R5) is increased and certified. Another skill barrier is insufficient domain knowledge, which is a problem in technical fields. It impacts the conceptual phase in which knowledge of the domain is needed to come up with relevant research questions. Domain specific skill barriers make it unlikely that researchers and citizens become equals in fields which require the acquisition of extensive domain specific knowledge which is difficult to acquire. These findings are in accordance with existing literature as they provide evidence for Haklay (2018)'s claim that time and knowledge constraints limit the feasibility of co-created CS.

Similarly, diverging interests (R8) of researchers and citizens cause researchers to exclude or limit citizens control over the early phases of the research process, in which the direction of the research project is decided on. It is especially difficult when researchers pursue research-driven goals and neglect citizen interests (oftentimes social goals) (R1). These findings are in conformance with research that suggests that goal alignment is challenging is CS projects (Powell & Colins, 2009). It adds to the literature by showing that (expected) challenges related to goal alignment are even more pronounced in co-creation projects.

Task completion in certain phases: Other barriers impact *only* task involvement in *certain* research phases. Laws and regulations (R14), e.g. for data privacy, make (co-created) CS more difficult. Particularly issues related to dealing with human data can cause researchers to limit task involvement in the empirical and analysis phase. However, typically, researchers did not provide these issues as the main reason for not pursuing co-creation. These findings confirm recent arguments that project owners need to pay careful attention to federal laws to avoid ethical and legal violations (Robinson et al. in Hecker & Haklay et al., 2018). They also add to the literature by showing that laws and regulations are an obstacle, however one, that is not decisive.

7.2 Platform solutions to overcome barriers to transitioning to co-creation

Based on the findings, this section evaluates to which extent different platform types can help overcome barriers to transitioning to co-creation. In the following, each platform type will be assessed, showing their benefits ("solutions for") and limitations ("provides no solution for") with regards to the barriers to transitioning to co-creation.

	Provides solution for barrier	Provides no solution for barrier	Provides alternative solutions for
Hosting platforms	R4, R5, R6, R7b, R11, R12, R14	R1, R3, R7b, R8, R9	R2, R10, R13
Listing platforms	R1, R2, R4, R7a, R7b, R12	R6, R8, R11	R3, R5, R9, R10, R13, R14
Service platforms	R7b, R12, R14	R1. R2, R3, R5, R7a, R8, R9, R10, R13	R4, R6, R11
Engagement platforms	R7b, R11	R1, R2, R4, R6, R8, R9, R13, R14	R3, R5, R10
Labor platforms	R4, R12	R1, R2, R3, R6, R8, R9, R10, R11, R13, R14	R5, R7
Crowdsourcing platforms	R5, R6, R7, R8, R12, R14	R1, R2, R3, R9, R10, R13	R4, R5

Table 13 Platform barrier solution matrix

7.3 Hosting Platforms new

Based on the findings, this section evaluates to which extent different platform types can help overcome barriers to transitioning to co-creation. In the following, each platform type will be assessed, showing their benefits ("solutions for") and limitations ("provides no solution for") with regards to the barriers to transitioning to co-creation.

	Provides solution for barrier	Provides no solution for barrier
Hosting platforms	R4, R5, R6, R7b, R11, R12, R14	R1, R3, R7b, R8, R9
Listing platforms	R1, R2, R4, R7a, R7b, R12	R6, R8, R11
Service platforms	R7b, R12, R14	R1. R2, R3, R5, R7a, R8, R9, R10, R13
Engagement platforms	R7b, R11	R1, R2, R4, R6, R8, R9, R13, R14

Labor platforms	R4, R12	R1, R2, R3, R6, R8, R9, R10, R11, R13, R14
Crowdsourcing platforms	R5, R6, R7, R8, R12, R14	R1, R2, R3, R9, R10, R13

Table 14 Overview of solutions provided by platform type

<u>Hosting platforms</u>

Hosting platforms facilitate the creation and management of CS projects.

Key interaction	Distinct or core functions
Direct interaction between interested contributors (e.g. citizens) and project initiators (e.g. researchers) that make use of the contributions (i.e. two- or multi-sided platform)	Combination, comprised of 1) an existing crowd or community on the platform, 2) tools enabling group interaction and coordination and 3) the capability to crowdsource the collection, processing or analysis of large data volumes.

Table 15 Summary of characteristics of hosting platforms

The platforms reduce (1) barriers due to researchers lack of skills for co-creation (R4), (2) barriers of will and ability of citizens (R5, R6, R7b), (3) barriers related to co-creating with a large crowd (R11) and (4) bureaucratic and legal barriers (R12, R14).

Benefits: First, hosting platforms provide solutions to complement researcher's skill set (R4). These solutions include offering technical expertise and skills to communicate with and coordinate volunteers. Second, hosting platforms provide support in volunteer education and motivation (R7). The analysis shows that hosting platforms increase volunteer's skills to perform a task more accurately and help to attract and retain participants through various mechanisms (R9). However, while hosting platforms provide solutions for an experienced lack of participant motivation, they are not able to remove the misconception of citizen's lack of interest to participate in the project. Third, hosting platforms facilitate large-scale CS projects by providing the tools necessary to coordinate a large (dispersed) group of participants (R11). Consequently, this helps researcher overcome barriers to team development. Lastly, hosting platforms help to reduce researcher's time burden (R12): they assist in matching citizen skills and tasks, coordinating and training volunteers, managing project-related processes, and overcoming legal barriers by ensuring compliance to data security and privacy.

Limitations: However, it is also shown that hosting platforms have several limitations. First, they do not address the alignment of researcher's career aspirations with CS activities (R8), as they cannot change the science system. Solutions are missing to adjust the funding system (R13) to co-creation.

Another frequently mentioned limitation concerns the development of team spirit (R13) due to lack of offline interaction, as the majority of activities are done online.

The literature analysis showed that hosting platforms help researchers to build projects, and match interested participants with projects (Franzoni & Sauermann, 2014). These findings extend the literature by showing that a great advantage of hosting platforms is that they provide support in project operations, in addition to infrastructure to conduct a project, thereby reducing the time burden placed on researchers. The greatest limitation of hosting platforms is that they cannot guarantee that team development barriers are overcome. Their services and features are targeted to facilitating contributory projects rather than co-created projects.

7.4 Listing platforms

Listing platforms help researchers to promote their CS project to potentially interested contributors and network with other researchers that are interested in CS projects.

Key interaction	Distinct or core functions
Direct interaction among researchers (i.e. network), and between researchers as project initiators and citizens as interested contributors (i.e. two- or multi-sided platform)	Service, including 1) an existing crowd on the platform, 2) tools facilitating public outreach and science communication, 3) a network of researchers and partners to leverage and exchange knowledge on CS

Table 16 Summary of characteristics of listing platforms

Listing platforms reduce (1) barriers of will and ability of researchers (R1, R2, R4), (2) barriers related to researcher's expected and experienced lack of citizen engagement (R7a, R7b) and (3) barriers related to researcher's limited (time) capacity (R12).

Benefits: Listing platforms offer solutions to change researcher's resistance (R1) in undertaking CS or to align CS activities with researcher's career aspirations. It was shown that some listing platforms engage in lobby work for CS to achieve greater acceptance of CS across disciplines and the science community. Those actions also address funding bodies (R13), aiming to facilitate funding for CS. Further, listing platforms can reduce researcher's knowledge- and skill-gaps (RR5) on co-creation through sharing best practices obtained from a variety of projects and managing science communication for the project. Additionally, listing platforms allow researchers to network and exchange knowledge on CS among their research peers who are interested or conducting CS. Solutions are provided to increase citizen engagement and retainment (R7) through communication and promotion strategies used for the project. Considering deviations between researcher's expected and actual level of citizen engagement (R7a), listing platforms offer advice and consultation on potential factors that might truly hinder citizen participation. Recommendations comprise, among others, the project design or a lack of targeted promotion strategies.

Limitations: Listing platforms sometimes struggle to provide project-specific advice on co-creation (R5). They draw from experience obtained from other researchers and projects in similar settings, but with co-creation being uncommon across several disciplines, the insights are often not generalizable. Listing platforms do not help tailor project designs to particular citizen circumstances or demographics (R6). Further, listing platforms can do little to ensure actual group alignment (R8) or increase team spirit (R10), as they are not an active coordinator within the project.

These findings are in accordance with existing literature which show that listing platforms are advocates for CS, act as knowledge and support centers (Newman et al., 2012), provide help with coordination (i.e. matching) (Franzoni & Sauermann, 2014; Hecker et al., 2018). It adds to the literature by showing that these functions are not only present in selected individual listing platforms such as SciStarter, but also across different national and international listing platforms. It adds to the literature by showing that these functions are key functions for overcoming barriers to co-created CS. However, there is still a limit to listing platforms since they do not promote co-creation in itself.

7.5 Service platforms

Product service platforms offer to develop, provide and maintain a (standardized) technical infrastructure for researcher's CS project.

Key interaction	Distinct or core functions
Technological infrastructure is shared between researchers or citizens (i.e. technical users and beneficiaries alike), and can be customized by either party (i.e. product platform)	Service, including 1) design, development and maintenance of a technical system, 2) customization of features or system, 3) built-in standardized work flows

Table 17 Summary of characteristics of product service platforms

Service platforms reduce (1) barriers related to researcher's experienced lack of citizen engagement (7b), (2) barriers related to researcher's limited (time) capacity (R12) and (3) legal barriers (R14).

Benefits: Service platforms can help researchers to increase citizen motivation and retainment (R7) through building in mechanisms such as gamification. As most service platforms cover technical design, development, and maintenance, they reduce the researcher's burden on obtaining these skills (R4) themselves or within their team, and time-intensive and costly technical maintenance (R13, R15).

Lastly, most also have solutions in place that ensure legal compliance (R14) the project's activities with existing data protection and privacy regulations.

Limitations: On the other hand, it was found that service platforms do not offer solutions to barriers of will (R1, R2, R3) of researchers as well as barriers of ability of citizens. As technical providers, service platforms are focused on the technical aspect of enabling CS and are therefore not acting as a promoter or educator of CS. Researchers using service providers are mainly seeking freedom and autonomy to design the project according to their project needs, which service platforms offer. In this regard, service providers install and tailor functions towards increasing citizen engagement, however, they do not affect researcher's expectations on citizens' engagement levels. Further, as technical providers, service platforms do not cover barriers to team development such as building mutual trust or personal relationships (R8, R9, R10).

The literature review showed that some service platforms could ease technical and sometimes financial burdens placed on CS projects (e.g. Hummer & Niedermeyer, 2018). These findings extend the literature by showing that service platforms help researchers to operate CS projects, and potentially also co-created CS projects. However, in contrast to other platforms like listing platforms, they do not evoke system changes.

7.6 Engagement platforms

Community engagement platforms help users to communicate, share and exchange information among members of the group to improve community engagement and motivation.

Key interaction	Distinct or core functions
Community engagement platforms help users to communicate, share and exchange information among members of the group to improve community engagement and motivation.	Service, including 1) an existing crowd or community on the platform, 2) features facilitating communication, group interaction and community building

Table 18 Summary of characteristics of engagement platforms

Engagement platforms reduce (1) barriers of will of citizens (R7b) and (2) barriers relating to co-creating with a large crowd (R11).

Benefits: Engagement platforms can help researchers to increase citizen engagement (R7) by facilitating communication and interaction between parties, as well as community building. They facilitate relationship building and group coordination, especially in large-scale, dispersed teams that depend on digital means to facilitate interactions (R11).

Limitations: Engagement platforms do not support researchers in overcoming barriers of ability of researchers and citizens alike (R4, R5). They also do not solve barriers of will from researcher's perceptions, career aspirations, and desire to adhere to good scientific practice (R1, R2, R3). Engagement platforms cannot offer solutions to efficiently align diverging project member interests or to build mutual trust and respect in an online environment (R8, R9). The platforms in the thesis' sample do not support offline interaction (i.e. face meetings) which are essential for co-creation. Lastly, engagement platforms also do not provide help with funding barriers, and sometimes legal issues arise due to personal data present on the platform. Finally, because engagement platforms are not targeted specifically at CS, they do not provide targeted support to researchers.

These findings confirm and extend the existing CS literature which had already established that engagement platforms can help citizen engagement, for example through asynchronous discussion forums which encourage an interactive debate between researchers and citizens (Raddick et al., 2010). These findings extend the literature by showing that engagement platforms can be beneficial for but do not suffice for removing barriers to co-creation, e.g. because offline interaction is not supported.

7.7 Labor platforms

Labor platforms help researchers to outsource defined tasks to a crowd or (specialized) individuals. Researchers compensate citizens through monetary payment. In comparison to the previous platform types, labor platforms' main field of application is in the commercial area.

Key interaction	Distinct or core functions
Direct interaction between citizens (i.e. freelancers) as task fulfillers and researchers as crowdsourcers who make use of citizens contributions (i.e. two- or multi-sided platform)	Service, including 1) an existing crowd or community on the platform, 2) outsource research or non-research related tasks, 3) task coordination (mainly by matching citizen's skill to the task)

Table 19 Summary of characteristics of labor platforms

Benefits: By allowing researchers to outsource tasks, such as the design of marketing materials, to a crowd of freelancers / workers, labor market platforms help overcome skill barriers (R4) of researchers, and help reduce the time burden (R10) placed on researchers in CS projects.

Limitations: Relationships on labor market platforms are of a transactional nature where researchers hire citizens for certain tasks. Citizens and researchers do not engage as equal partners, rather, citizens are used as a tool (R1). When the "job" is completed, typically the engagement (R7) ends, and due to the short-term nature of the relationships, teams do not form (R10).

These findings are in line with scholars who describe labor market platforms as encouraging the use of workers (Pittman & Sheehan, 2016). In the literature, it was suggested that financial incentives could be beneficial for co-creation because they provide "compensation" or extra "motivation" for some individuals (Kittur et al., 2011), however this thesis finds that financial compensation actually hindered co-creation because financial incentives became more important than shared social goals, which are key to co-creation.

7.8 Crowdsourcing platforms

Crowdsourcing (contest) platforms help researchers to systematically process solutions for idea generation and / or issue resolution, improving consensus building and coordination. Like labor market platforms, crowdsourcing (contest) platforms are mainly applied in the commercial field.

Key interaction	Distinct or core functions
System or platform owner acts as intermediary between researchers who seek solutions or ideas and citizens who provide solutions or ideas (i.e. integrator)	Service, including 1) an existing crowd or community on the platform, 2) features for ideation and consensus building 3) task coordination (mainly by matching citizen's skill to the task)

Table 20 Summary of characteristics of crowdsourcing platform

Crowdsourcing (contest) platforms were found to reduce (1) barriers to ability of citizens, and citizen engagement (R5, R6, R7), (2) barriers to researcher's limited (time) capacity and (3) legal barriers.

Benefits: Crowdsourcing (contest) platforms help overcome citizen skills barriers by providing support in task decomposition. Through task decomposition, tasks become less complex and more easily solvable. By providing guidance on project design, they make projects more appealing to citizens, increasing engagement (R7). Engagement is also increased through gamification features that are commonly in place. Some crowdsourcing (platforms) also help structure teamwork and facilitate group interactions, e.g. through virtual team rooms. This facilitates co-creation with large crowds (R11). Finally, through customizable infrastructures (e.g. voting functions) they help support ideation and problem-solving processes, which are particularly relevant, the former being particularly relevant to early research phases.

Limitations: While crowdsourcing platforms are well suited to provide operational support, they do not strategically help remove barriers to transitioning to co-creation. Barriers of will and bureaucratic and administrative barriers are not addressed.

These findings extend the existing literature which had solely pointed out that crowdsourcing (contest) platforms helped with structuring work between individual members of the crowd, e.g. by helping to divide and integrate contributions (Franzoni & Sauermann, 2014). This thesis extends the literature by showing that crowdsourcing platforms can be particularly helpful, also in increasing engagement, and facilitating shared decision-making.

7.9 Implications

Theoretical implications: The analysis contributes to the growing body of literature that suggests that each type of CS project comes with benefits and challenges (Haklay, 2018). It shows that it is important to distinguish between factors that impact task involvement versus co-decision-making, because there are different factors that hinder transitioning in each direction. Further, it shows that barriers to co-created projects need to be addressed by different (platform-based) solutions than those of CS. Some barriers in CS are also barriers to transitioning to co-creation (e.g. funding), however, some are stronger in co-creation (e.g. capacity constraints), and others of less relevance (e.g. legal and ethical barriers).

Practical implications: Project owners and participating citizens should be aware of potential hurdles to transitioning to co-created CS projects. Co-created projects will only be successful for topics which can sustain the interest of researchers and citizens alike. Researchers should not presume levels of interest, and should be willing to spend significant time investments, also on non-research related tasks. To allow for citizens to build scientific literacy, and for mutual respect and trust to establish, projects should be set up as long-term projects. The greatest value of online platforms lies in promoting exchange between researchers, sharing knowledge and best practices. For project implementation, project teams can also cherry pick services and features of each platform to build their own "co-creation-toolbox".

7.10 Limitations

The limitations on external and internal validity of this thesis must be acknowledged. In terms of the generalizability of the identified barriers to co-created CS, the authors recognize that the findings might not be applicable across different national contexts. The majority of the primary data used was gathered from CS projects that were conducted in Europe, particularly Germany and Austria, and thus, were embedded in the same or similar institutional context. Therefore, the outlined barriers to co-creation might not be equally experienced by all researchers, given varying national contexts.

In terms of generalizability of identified platform solutions, the study could have benefited from including more varied platform cases for each platform type into the sample. This could underline the diverse range of functionalities offered by one platform type. To increase comparability between several platform types, standardized data collected from multiple platforms for each platform type could have reflected the variances in platform's functions in a more thorough way. However, due to the collection of secondary data, this limitation could partially be mitigated.

In terms of internal validity, this study tried to balance two philosophical viewpoints which can be particularly challenging. Some barriers form part of subjective impressions of the respective respondent (i.e. subjectivism) and others result of factual circumstances (i.e. objectivism). While subjective values enable to gain an in-depth understanding of a certain phenomenon and its causalities, they are not easily transferable to other participants (Saunders et al., 2009). However, by evaluating the prevalence of participant statements on a certain theme, the authors were able to identify general patterns across the sample.

The authors assume that additional interview candidates might have brought up new viewpoints. While a certain level of theoretical saturation has been reached, as the authors observed repetitive patterns among the participant responses, they emphasize that the study is not exhaustive.

Finally, due to time constraints, for some platforms only limited insights could be received. Sometimes, services and features were not explicitly stated in the raw data received, and additional interviews could not be set up. A large-scale survey could be applied in the future to gain further insights.

7.11 Avenues for future research

The authors see potential avenues of future research in a number of areas. In general, provided the purpose of this study is to investigate a novel topic through an exploratory analysis, there is a need for future research to deductively test and validate the findings in this thesis.

Address the delimitations: Future research could address the delimitations of this study, for example, investigate the phenomenon of low adoption of co-creation in different geographical locations, or include the perspective of citizens. Second, it could also research factors that did not reach theoretical saturation, e.g. organizational barriers. Lastly, with regards to platform-based solutions, it could investigate differences within a platform type.

Research community driven CS: This study focused its analysis on transitioning from lower forms of CS to co-creation. Future research could analyse the movement from higher forms of CS (e.g. extreme CS projects) to co-creation, since co-creation could just as likely be community driven as researcher driven.

Investigate practice and impact: As already suggested by other scholars (Robinson et al., 2018), future research is needed on the practice and impacts of co-creation. The authors encourage researchers conducting (co-created) CS to publish best-practice reports based on their experiences, and highlight the benefits co-created CS allowed to achieve.

Explore stakeholders' roles: As project owners can benefit from support from stakeholders in CS other than online platforms, the role of other stakeholders which have not been the focus of attention could be analyzed. Since the results showed that in CS projects, problems can arise due to diverging interests, also from external partners, one could also shed light on the interests of different parties that may hamper project success, and derive recommendations for choosing suitable practice partners.

Funding mechanisms: As funding turned out to be an important barrier, future research could investigate alternative funding mechanisms in relationship to CS. This has already been suggested by other scholars, such as Sauermann (2019) who called for a comparison between the mechanisms for involving citizens in crowdfunding and CS. Potentially, citizens who are willing to fund research projects are (more) interested in contributing to a project with time and cognitive abilities, than other individuals. This could be a topic for investigation.

7.12 Conclusion

This thesis finds that there are five types of barriers hindering researchers to transition to co-creation: Barriers of (1) will and (2) ability of the researcher, (3) barriers of ability of the citizen, (4) barriers to citizen engagement and team development, and (5) bureaucratic and administrative barriers. Individual online platforms provide limited help to remove these barriers. However, when the services and features of several platforms are combined into a value-creating whole, platforms provide ample support for project implementation. However, more far-reaching solutions are needed to remove system-related barriers.

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9. Appendices

9.1 Classification and short description of platform intermediaries

(based on information provided on platform websites, open source encyclopedias, academic journals, and business directories)

Name	Platform type	Short description of the platform	Link to platform
Zooniverse	Project hosting platform	The Zooniverse is an open citizen science platform with both project building and hosting capabilities. Zooniverse projects require the active participation of human volunteers to complete research tasks. Projects have been drawn from disciplines including astronomy, ecology, cell biology, humanities, and climate science.	https://www.zooniverse.org/
CitSci	Project hosting platform	CitSci.org supports individual research pursuits by providing tools and resources for the entire research process including: creating new projects, managing project members, building custom data sheets, analyzing collected data, and gathering participant feedback. Members of CitSci.org are encouraged to investigate their own scientific questions or join an existing project as a volunteer.	www.citsci.org
Science@home	Project hosting platform	ScienceAtHome does research on quantum physics, citizen science and gamification. ScienceAtHome also develops games that contribute to scientific research, and studies how humans interpret information to achieve results superior to some algorithmic approaches. Most ScienceAtHome games are casual games and require no formal scientific training.	https://www.scienceathome.org/
iNaturalist	Hybrid (hosting & community engagement platform)	iNaturalist is a citizen science project and online social network of naturalists, citizen scientists, and biologists built on the concept of mapping and sharing observations of biodiversity across the globe. Observations recorded with iNaturalist provide valuable open data to scientific research projects, conservation agencies, other organizations, and the public	inaturalist.org
Socientize	Hosting platform	The SOCIENTIZE project will coordinate all agents involved in the citizen science process, setting the basis for a new open science paradigm. The project will promote the usage of science infrastructures composed of dedicated and external resources, including professional and amateur scientists. SOCIENTIZE provides online assistance in performing tasks that require human cognition, knowledge or intelligence such as image classification, transcription, geocoding etc.	http://socientize.eu (current platform) http://pybossa.socientize.eu/pybossa/ (new platform)

Bürger schaffen Wissen	Project listing platform	Bürger schaffen Wissen is a German citizen science website which provides a listed overview of (mainly) national citizen science projects. It provides knowledge on citizen science and establishes a network for citizen science among researchers and organizes citizen science conferences.	https://www.buergerschaffenwissen.de/
Iedeeren Wetenschapper	Project listing platform	Iedeeren Wetenschapper is a Dutch citizen science website which provides a listed overview of (mainly) national citizen science projects. It connects people and citizen science projects and helps researchers to communicate to the public.	https://www.iedereenwetenschapper.be/
Österreich forscht	Project listing platform	Österreich forscht is an Austrian citizen science website which provides a listed overview of (mainly) national and registered citizen science projects. It establishes lobbying campaigns through networking and sharing knowledge on citizen science.	https://www.citizen-science.at/
Schweiz forscht	Project listing platform	Schweiz forscht is a Switzern citizen science website which provides a listed overview of citizen science projects in DACH region. It provides a network for researchers to exchange citizen science practices.	https://www.schweiz-forscht.ch/
SciStarter	Project listing platform	SciStarter recruits, trains, and equips people for citizen science research projects in need of their help.SciStarter is a collection of web tools and an event-based organization that connects people and citizen science projects, events, and tools..	www.scistarter.com
Amazon MTurk	Labor market platform	Amazon Mechanical Turk (MTurk) is a crowdsourcing website for businesses (known as Requesters) to hire remotely located crowdworkers to perform discrete on-demand tasks (i.e. microtasks) that computers are currently unable to do. Employers post jobs known as Human Intelligence Tasks (HITs), such as identifying specific content in an image or video, writing product descriptions, or answering questions, among others. Workers, colloquially known as Turkers or crowdworkers, browse among existing jobs and complete them in exchange for a pay rate set by the employer.	https://www.mturk.com/
Upwork	Labor market platform	Upwork, formerly Elance-oDesk, is a global freelancing platform where businesses and independent professionals connect and collaborate remotely. Upwork allows clients to interview, hire and work with freelancers and agencies through the company's platform. The platform aims to reduce the time it takes to find, vet and hire freelancers.	https://www.upwork.com/
Freelancer.com	Labor market platform	Freelancer is a global crowdsourcing marketplace website, which allows potential employers to post work for site members (i.e. freelancers) while bidding on in a competitive tender process. The site also allows members to host and enter contests for which prize money is offered as a reward. Freelancers and employers develop profiles on the site as they offer, win and complete work and write and receive reviews of people they work with or for.	https://www.freelancer.com/
Fiverr	Labor market platform	Fiverr is an online marketplace for freelance services. Fiverr is a company built on the model of listing temporary work positions. Fiverr serves to allow listing and applying for small one-off jobs, or gigs, online.	https://www.fiverr.com/
Clickworker	Labor market platform	Clickworker is a global crowdsourcing marketplace which connects job suppliers and seekers. Clickworker utilizes the knowledge and capacity of the crowd (i.e. Clickworkers)	https://www.clickworker.com/

		who complete tasks on a piece rate basis. Most of these tasks are part of a larger, more complex, project.	
InnoCentive	Crowdsourcing (contest) platform	InnoCentive is an open innovation and crowdsourcing company which enables organizations to put their unsolved problems and unmet needs, which are framed as ‘Challenges’, out to the crowd to address. In the case of InnoCentive, the crowd can either be external (i.e. their network of problem solvers) or internal (i.e. an organization's employees, partners or customers).	https://www.innocentive.com/
Topcoder	Crowdsourcing (contest) platform	Topcoder is a crowdsourcing company with an open global community of designers, developers, data scientists, and competitive programmers. The community of professionals participates in tournament-based competitions. Topcoder pays community members for their work on the projects and sells community services to corporate, mid-size, and small-business clients.	https://www.topcoder.com/
Crowdicity	Crowdsourcing (contest) platform	Crowdicity is an idea management software solution that can be used to harness the ideas of your employees, customers, and stakeholders to drive innovation.	https://crowdicity.com/
IdeaScale	Crowdsourcing (contest) platform	IdeaScale is a cloud-based software company that licenses an innovation management platform employing the principles and practices of crowdsourcing. Idea givers can submit ideas, comment and vote on other ideas. Once a promising idea has been identified, the software allows teams to form around the idea. The team can add more information to the idea, refine it, propose it to leadership and the best ones are selected using decision matrix capabilities.	https://ideascale.com/
OpenIdeo	Crowdsourcing (contest) platform	OpenIDEO is a collaborative platform for creative work which connects idea seekers and idea givers. There are three major steps for crowdsourcing on OpenIDEO: challenge, events, alliances. The “Challenges” part is an open idea accelerator where worldwide users are connected to the platform. The “Events” part creates opportunities for users to participate, engage actively, and collaborate with innovators. The “Alliances” part provides a sense of community that supports its users to connect, design solutions together, and build partnerships	https://www.openideo.com/
ExpertLens	Crowdsourcing (consensus building) platform	ExpertLens provides a platform for engaging a selected crowd in a remote consensus building process. It enables clients to reach consensus on complex subject matters through online surveying or moderated discussion..	https://www.rand.org/pubs/tools/expertlens.html
Twitter	Community engagement platform	Twitter is a microblogging and social networking service on which users post and interact with messages known as "tweets". Registered users can post, like, and retweet tweets, but unregistered users can only read them.	https://twitter.com
Facebook	Community engagement platform	Facebook, Inc. is an online social media and social networking service company. Users can post text, photos and multimedia which is shared with any other users that have agreed to be their "friend". Users can also use various embedded apps, join common-interest groups, and receive notifications of their friends' activities.	https://www.facebook.com/

Reddit	Community engagement platform	Reddit is a social news aggregation, web content rating, and discussion website. Registered members submit content to the site such as links, text posts, and images, which are then voted up or down by other members.	https://www.redditinc.com/
PatientsLikeMe	Community engagement platform	PatientsLikeMe is a for profit patient network and real-time research platform. Through the network, patients connect with others who have the same disease or condition and track and share their own experiences with the goal to improve outcomes. In the process, they generate data about the real-world nature of disease which forms the basis of numerous scientific publications.	https://www.patientslikeme.com/
iSpot	Hybrid (hosting & community engagement platform)	iSpot is an online community intended to connect nature enthusiasts of all levels. Registered users upload images of wildlife observations, identify species, and discuss their findings with other members. This is intended to provide opportunities to learn more about the wildlife citizens have observed, and also provides a database of observations which is made available for scientific analysis.	https://www.ispotnature.org/
Lingscape	Product / Service Platform	App in which citizens can collect linguistic data about their surroundings (e.g. taking pictures on signs that contain language) and share these data between each other	https://lingscape.uni.lu/
SPOTTERON	Product / Service Platform	SPOTTERON is a smartphone app system (Android and iPhone) for documenting localised and specific sightings. The collected data is edited for evaluation and represented on maps. It is a payable service.	https://www.spotteron.net/de/
Pybossa	Product / Service Platform	PYBOSSA is an open-source crowdsourcing platform that allows researchers, civic hackers and developers to create projects that need help to solve problems, analyze data or complete challenging tasks that can’t be done by machines alone, but require human intelligence.	https://pybossa.com/
Epicollect	Product / Service Platform	Epicollect.net provides a web and mobile app for the creation of forms (questionnaires) and generation of freely hosted project websites for data collection. Data are collected (including GPS and media) using multiple phones. All data can be viewed centrally (using Google Maps / tables / charts).	http://www.epicollect.net/
Experimental Tribe	Product / Service Platform	Experimental Tribe is a web platform designed for scientific gaming and social computation. Experimental Tribe help researchers in the realization of their own web-experiments by accomplishing those necessary and non-research related tasks, including human resource management. In this way, researchers can solely focus on the implementation of the core part of their experiment while keeping full control over their own experiment and full ownership of the data they gather.	http://www.xtribe.eu/
EU.Citizen-Science	Other	The EU-Citizen.Science project is supporting the development of citizen science across Europe by creating a central platform for sharing knowledge, initiating action and supporting mutual learning.	http://eu-citizen.science

9.2 Barriers to transitioning to co-created citizen science and the relationships that make up the barrier

Barrier			Relationships between categories (nodes) that make up the barrier						Consequence for transitioning to co-creation	
Type	**No.**	**Description**	**External environment**	**Discipline and scientific community**	**Project type**	**Group (team)**	**Researcher**	**Citizen**	**Task involvement is not expanded**	**Decision-making is not shared**
Will	R1	Researchers' perception of (co-created) citizen science and its uncertain nature		Discipline & study design	Research driven / socially driven		Perceptions, attitudes, etc.	Circumstances & demographics	**x**	**x**
	R2	Researchers career opportunities & desire to publish in peer reviewed journals	Science system	Scientific community	Research driven / socially driven Small scale vs. large scale		Perceptions, attitudes, etc. Seniority		**x**	**x**
	R3	Researcher's desire to adhere to good scientific practice		Scientific community	Research driven / socially driven		Perceptions, attitudes, etc. Seniority		**x**	**x**
Ability	R4	Researchers' lack of knowledge and skills		Discipline & study design Scientific community		Team size Team members	Knowledge & skills Perceptions, attitudes, etc.	Knowledge & skills	**x**	
Ability	R5	Citizen's lack of knowledge and skills (scientific literacy & domain knowledge)		Discipline & study design	Long-term vs. short-term	Team size Team members	Capacity (time) Knowledge & skills	Knowledge & skills	**x**	**x**
	R6	Citizens' circumstances and demographics		Discipline & study design	Online vs. offline projects Long-term vs. short-term School project		Perceptions, attitudes, etc.	Engagement Circumstances & demographics	**x**	
Engagement & Team	R7	Expected (a) and experienced (b) lack of citizen engagement (Barrier to forming a team)	Society	Discipline & study design Scientific community	Research driven / socially driven Small scale vs. large scale		Knowledge & skills Perceptions, attitudes, etc.	Engagement	**x**	**x**

	R8	Diverging interests (Barrier to forming a team)			Research driven / socially driven		Perceptions, attitudes, etc.	Engagement Perceptions, attitudes, etc.	**x**	**x**
	R9	A lack of mutual trust & respect (Barrier to norming a team)	Funding agencies Society	Discipline & study design	Long-term vs. short-term		Perceptions, attitudes, etc. Capacity (time)	Engagement	**x**	**x**
	R10	Missing team spirit (Barrier to performing in the team)			Online vs. offline			Engagement Circumstances & demographics	**x**	
	R11	Barriers related to co-creating with a large crowd			Small scale vs. large scale Online vs. offline	Team size				**x**
Bureaucratic & administrative	R12	Researchers' limited capacity (time)				Team size Team members	Capacity (time) Seniority		**x**	
	R13	Lack of sufficient, long-term, and flexible funding	Funding agencies Government		Research driven / socially driven Long-term vs. short-term		Seniority Perceptions, attitudes, etc. Capacity (time)		**x**	
	R14	Legal and ethical barriers	Laws & ethics		Online vs. offline				**x**	
	R15	Organizational barriers (theoretical saturation not reached)	Organization						**x**	**x**

Legend: **Dimensions:**

- External environment: a) Organization, b) Science system, c) Funding agencies, d) Government, e) Society, f) Laws & ethics
- Discipline & scientific community: a) Discipline & study design, b) Scientific community
- Project type: a) Small scale vs. large scale, b) Long-term vs. short-term, c) Online vs. offline, d) Research driven / socially driven, e) School project
- Group (team): a) Team size, b) Team members
- Researcher: a) Capacity (time), b) Knowledge & skills, c) Perceptions, attitudes, etc. d) Seniority
- Citizen: a) Engagement, b) Knowledge & skills, c) Circumstances & demographics

Table of Solutions to Barriers

Barrier			Solution	Solutions provided by each platform type						
Type	No.	Description	Solution / Mechanism	Hosting	Listing	Product service	Community engagement	Labor market	Crowdsourcing	Others
Will	R1	Researchers' perception of (co-created) CS and its uncertain nature	Facilitate formal and informal knowledge exchange Making CS known across domains	Promote CS[25] Lobby for CS[26]	Promote Lobby for CS					
	R2	Researchers career opportunities & desire to publish in peer reviewed journals	Reward CS activities Promote CS among (science system) decision-makers		Lobby for citizen					
	R3	Researcher's desire to adhere to good scientific practice	Ensure methodological rigor & shared decision-making Establish and share best practices	Enable peer review and/or provide feedback	Enable peer review and/or provide feedback		Enable peer review and/or provide feedback			

[25] Promote citizen science = only knowledge-based dissemination on what CS is and how to conduct it (e.g. best practices, white papers etc.)
[26] Lobby for citizen science = set up a CS community (e.g. cooperations, conferences, networks)

	R4	Researchers' lack of knowledge and skills	Establish and share best practices Foster exchange among scientists Hire new team members, collaborate with partners or expand skill sets	Provide learning material and best practices Consult and advice on CS project Complement with communication and coordination skills Complement with technical skills	Train researchers Provide learning material and best practices Consult and advice on CS project Enable researchers to network Complement with (science) communication skills	Complement with technical skills		Complement with specialized skills	Provide learning material and best practices	Provide learning material and best practices on CS Enable researchers to network
will + ability	R5	Citizen's lack of knowledge and skills (scientific literacy & domain knowledge)	Educate citizens Decompose tasks	Train citizens Provide learning material and best practices Offer feedback mechanisms Advice on task decomposition Incorporate gamification	Provide learning material and best practices		Train citizens Provide learning material and best practices	Identify skilled citizens Advice on task decomposition	Train citizens Provide learning material and best practices Offer feedback mechanisms Advice on task decomposition	Provide learning material and best practices on CS
	R6	Citizens' circumstances and demographics	Collaborate with lay experts to frame tasks Design the study with citizens	Customize features or tools Coordinate and/or train volunteers		Customize features or tools			Customize features or tools Coordinate and/or train volunteers Manage project process	
Team development	R7	Citizens (expected) lack of engagement	Capture and retain citizens interest Collaborate with external parties to identify and recruit interested participants Build a community Provide targeted interactions and tasks Be transparent	Provide access to existing crowd Advertise / spread info on project Incorporate gamification Match citizen interest to project topic Set up communication channels	Provide access to existing crowd Advertise / spread info on project Manage (science) communication Match citizen interest to project topic Set up communication channels Consult and advice on CS project	Provide access to existing crowd Advertise / spread info on project Incorporate gamification Set up communication channels	Provide access to existing crowd Advertise / spread info on project Incorporate gamification Match citizen interest to project topic Set up communication channels	Provide access to existing crowd Offer monetary compensation	Provide access to existing crowd Advertise / spread info on project Incorporate gamification Facilitate consensus building Match citizen interest to project topic	Advertise / spread info on CS

			Build mutual trust and respect and team spirit						Set up communication channels	
	R8	Diverging interests	Find a research topic of equal relevance to all						Facilitate consensus building	
	R9	A lack of mutual trust & respect	Facilitate trust building and increase mutual respect through various activities Conduct long-term projects		Provide quality seal for CS projects					
	R10	Missing team spirit	Conduct offline projects	Arrange offline meetings	Arrange offline meetings		Arrange offline meetings			
	R11	Barriers related to co-creating with a large crowd	Use digital tools with large crowds Employ new governance forms	Customize features or tools Coordinate and/or train volunteers		Customize features or tools	(Enables to) Coordinate and/or train volunteers		Coordinate large crowds Coordinate and/or train volunteers	

Bureaucratic	R12	Researchers' limited capacity (time)	Divide tasks among team members Distribute tasks to partner organizations	Match tasks to volunteer Coordinate and/or train volunteers Manage project process	Manage (science) communication Coordinate and/or train volunteers	Manage technical maintenance	(Enables to) Coordinate and/or train volunteers	Match tasks to volunteer Outsource non-related tasks	Match tasks to volunteer Coordinate and/or train volunteers Manage (science) communication Manage project process	
	R13	Lack of sufficient, long-term, and flexible funding	Increase CS funding schemes and their flexibility Facilitation of change through partnerships and network Use alternative funding schemes	Promote CS[27] Lobby for CS[28]	Promote CS Lobby for CS					Promote citizen science Lobby for CS Coordinate CS activities across projects
	R14	Legal and ethical barriers	Seek participant consent and/or do not collect personal data Seek legal support	Comply to data security and privacy laws	Provide legal advice	Comply to data security and privacy laws	Comply to data security and privacy laws but ethical issues	Comply to data security and privacy laws but ethical issues	Comply to data security and privacy laws	
	R15	Organizational barriers	No barrier - Satisfaction with affiliate organization							

Table - **Overview of solutions provided by each platform type**

27 Promote citizen science = only knowledge-based dissemination on what CS is and how to conduct it (e.g. best practices, white papers etc.)
28 Lobby for citizen science = set up a CS community (e.g. co-operations, conferences, networks)

9.3 Interview guides

A) Interview guide for bespoke platform stakeholders

A note about the interview guide

This is a flexible interview guide for conducting semi-structured interviews. The order of and the specific questions asked will vary, and additional questions may be asked, and some may be omitted. Adjustments will be made by considering the participants' context and the flow of the conversation. The interview guide will not be sent to the interviewees beforehand to avoid potential bias in interviewee's responses. If an interviewee requests the questionnaire prior to the interview, only selected main questions will be sent.

Interview questions

Opening the interview

The authors briefly introduce themselves and the research field (i.e. citizen science and how it is applied in science). They remind the interviewee about his/her written consent (i.e. email confirmation) to record the interview and to use the input for the underlying study.

The authors walk the interviewee through the interview structure, telling them that questions about their experience with citizen science and with the specific platform are asked.

Part 1: Reference data and context of the interviewee

Introduction sentence: Before we start with the interview, we would like to get to know you better.

Main questions:

1. As a [position], what would you say are your main tasks? And very briefly in one or two sentences, what is your main research interest? What is your role in the [project]?

Part 2: General information on the citizen science project

Introduction sentence: Now, we are interested in learning about the citizen science project [name] that you [did / are doing] on [platform, if applicable].

Main question [the authors briefly summarize the citizen science project]:

1. Could you please give us a brief summary about the research project?

Follow-up questions:

1. Which tasks [are / were] performed by citizens? Please let us know why you decided to involve citizens in this way.
2. Which decisions [do / have] you share(d) with citizens? Please let us know why you decided to do this.

Part 3: Choosing an independent platform

Introduction sentence: We have seen that you have set up your own project website and/or platform. We'd like to speak a little bit about that now.

Main questions I [General information about the platform]:

3. What is the purpose of the platform?
4. Could you please describe the platform? What are its main features?

Follow-up questions:

5. Why did you decide to include these features? Why do you find these features helpful / important to have on a platform?
6. How or through which features does [platform] help you to involve citizens in particular research tasks?
7. How or through which features does [platform] help you to engage citizens in particular research decisions?

   Standardized explanation: By decision-making we mean the process of choosing among several alternative possibilities. Every decision-making process produces a final decision, which may or may not prompt action.

Main questions II [Choosing an independent platform]:

8. Why did you conduct your project with your own platform?
9. Did you check different platforms before deciding not to use another platform such as the Zooniverse?

Follow-up questions:

10. Did you decide to set up your own platform due to limits of existing platforms on the market? What are existing solutions missing?

Part 4: Barriers to co-creation

Introduction sentence: In the next part of the interview, we'd like to talk about so-called co-created citizen science projects.

Standardized explanation: We mean projects in which researchers and citizens share decision rights in an equal partnership throughout all research phases. As these projects are uncommon in research, we'd like to understand under which circumstances such projects make sense and don't make sense.

Main questions I [Barriers to co-creation]

11. What do you think about the usefulness and / or applicability of co-created projects?
12. When you think of the conceptualization of your project, did you consider engaging citizens more deeply (i.e. involving citizens in more tasks or sharing more decisions with them or both)?
13. From your experience, what are the barriers / challenges / obstacles / difficulties related to co-creation (i.e. projects in which researchers and citizens share decision rights in an <u>equal partnership</u> throughout <u>all</u> research phases)?

Part 5: Platform-based solutions for co-creation

Main questions I:

14. **How should a platform's products or services or features be designed to best support** scientists who want to engage citizens throughout all research phases as an equal partner, sharing decisions with them?

Introduction sentence:

In the last 15 minutes of the interview, we'd like to ask some specific questions about how your platform helps researchers engage citizens more deeply or co-create with them. From our interviews with researchers we know that researchers face certain challenges when wanting to co-create with citizens.

We'll show you these barriers, and would like to know if you agree or disagree with the statement, and then, if your platform offers any solutions to this problem and if so, which ones? You can also indicate if you can think of a solution to this problem.

So, let's start with the first barrier that researchers face.

1. *[Ask the following question, inserting the barriers a) through k)]*

   We know that [insert barrier a) through k) here]. This presents a barrier to engaging citizens more deeply in research. Does your platform offer any solutions to this problem? Which ones?

Individual level barriers:

a) ...some researchers struggle to gain **enough skilled participants** for their citizen science project, and especially maintaining them in the long-term
b) ...some **researchers lack certain skills**, e.g. communications skills, to engage with citizens more deeply
c) …some researchers with **certain seniority levels** (e.g. full professor vs. PhD student) find it more difficult to engage with citizens more deeply

Project level barriers:

d) ...some researchers have **methodological concerns**, e.g. with regards to ensuring the validity of data collected by citizens
e) ...some researchers face **issues with regards to data security and privacy** in citizen science projects
f) ...some researchers do **not want to share data or intermediary results openly** with a broad community
g) ...some researchers find it challenging to engage citizens more deeply or meaningfully in **certain project types**, e.g. those projects that engage a large number of citizens worldwide, compared to others

Organizational level barriers:

h) …some researchers do not receive **sufficient support and / or resources** (e.g. funding) from their research institutions

Ecosystem level barriers:

i) ...some researchers find that there exists a **lack of knowledge of citizen science** as a field, and a **lack of best practices** of conducting citizen science projects, especially those that engage citizens more deeply

j) ...some researchers who engage citizens in science **lack acceptance from peers** (i.e. fellow researchers)

k) …some researchers find that the **external environment**, e.g. the scientific community or government, does **not sufficiently support** citizen science especially at deeper citizen engagement levels (e.g., researchers have difficulties when publishing their citizen science work in peer-reviewed journals)

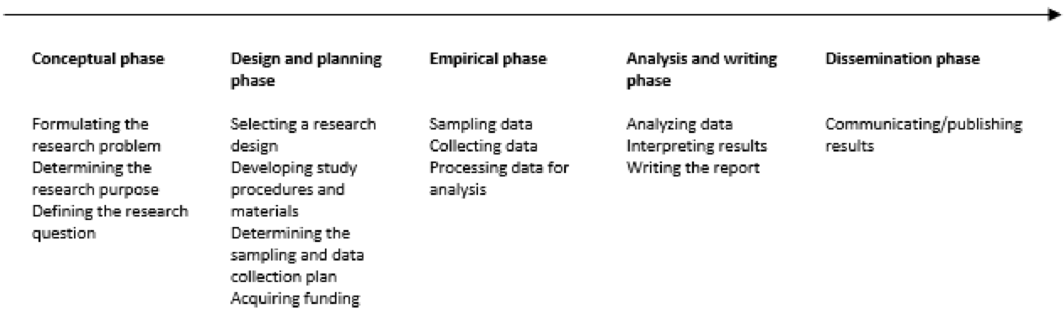
Ending the interview

Main question:

2. Is there anything else you would like to tell us about the role or function of platforms in citizen science that we did not talk about yet?

<u>**Vocabulary (standardized explanations):**</u>

- **Citizen science:** This refers to the voluntary and intended engagement of citizens (commonly referred to as “non-scientists”, the “crowd”, “citizen scientists”, “amateur scientists”, “volunteers”, the “public” or the “general population”) into the scientific research process.
- **Research phases:** Please have a look at this graph. It is a very simplified version of the scientific research process. There might be tasks missing. Please let us know if this is the case or if there is anything that is unclear to you.



- **Engagement / Involvement / Participation:** We mean that citizens actively contribute to the research project by using their cognitive abilities and/or knowledge assets. They complete tasks in one or many phases of the research project, for example in the empirical or conceptual phase. This goes beyond citizens being merely informed or consulted.
- **Decision-making:** By decision-making we mean the process of choosing among several alternative possibilities. Every decision-making process produces a final decision, which may or may not prompt an action.
- **Contributory (classic) citizen science:** We mean projects in which citizens do not receive any decision rights and in which they are involved in only few research phases. Most current projects, which usually limit public involvement to simple data collection, coding, processing, or analysis tasks, fall into this category.

- **Co-created citizen science:** We mean projects in which researchers and citizens share decision rights in an equal partnership throughout all research phases. Only few current projects fall into this category, as only few researchers involve citizens in the formulation of a research question, the development of a research design, or the study dissemination phase.
- **Barriers / challenges / obstacles / difficulties:** This can be anything that prevents the researcher from involving citizens in more phases and giving citizens more decision rights. It can be something that the researcher can influence or something that the researcher cannot influence easily. One might think of internal barriers linked to researcher's capabilities or external constraints, for example the context or situation the researcher is in, the resources that he / she has outside the team, the people around him / her, etc.
- **Online platform intermediary:** We mean the various online intermediaries that act as a link between researchers and citizens. You may know Zooniverse, the citizen science platform that hosts and lists projects, or Amazon MTurk, the labor market platform.
- **Multilevel analysis (individual, project, organizational, ecosystem level):**
    - The individual level comprises the smallest unit of analysis and includes aspects that can be attributed to an individual person such as one's values and beliefs.
    - The project level represents a structural aggregation of individuals and includes aspects that can be attributed to the project in which the individual is positioned. An example is the project's mission.
    - The organizational level represents a structural aggregation of individuals and includes aspects that can be attributed to the organization in which the individual is positioned. An example is the institution's (e.g. university's) mission.
    - The ecosystem level goes beyond an aggregation of individuals and includes the surrounding support system in which the individual person, the project, and the organization are embedded. The ecosystem level comprises, for example, of governmental regulations and societal norms.

B) Interview guide for researchers engaging in citizen science

A note about the interview guide

This is a flexible interview guide for conducting semi-structured interviews. The order of and the specific questions asked will vary, and additional questions may be asked, and some may be omitted. Adjustments will be made by considering the participants' context and the flow of the conversation. The interview guide will not be sent to the interviewees beforehand to avoid potential bias in interviewee's responses. If an interviewee requests the questionnaire prior to the interview, only selected main questions will be sent.

Interview questions

Opening the interview

The authors briefly introduce themselves and the research field (i.e. citizen science and how it is applied in science). They remind the interviewee about his/her written consent (i.e. email confirmation) to record the interview and to use the input for the underlying study.

The authors walk the interviewee through the structure of the interview and tell him/her that the interview starts with general questions on the interviewees' background and his/her conducted citizen science project(s), and that the interview continues with more detailed questions on citizen engagement, and ends with questions on the role of platform intermediaries in citizen science.

Part 1: Reference data and context of the interviewee

Introduction sentence: Before we start with the interview, we would like to get to know you better.

Main questions:

1. As a [position at university], what would you say are your main tasks? And very briefly in one or two sentences, what is your main research interest?

Part 2: General information on the citizen science project

Introduction sentence: Now, we are interested in learning about the citizen science project [name] that you [did / are doing] on [platform, if applicable].

Main question [the authors briefly summarize the citizen science project]:

2. Could you please give us a brief summary about the research project?

Follow-up questions:

- Who is and how many people are involved in the project organization?
- Are people involved in the project organization that are not professional scientists? How and why?

Part 3: Scope of engagement of citizens

Introduction sentence: Thanks for this brief introduction. It sounds like a very inspiring project. We'd like to learn more about the citizen engagement in [project] and understand why you are engaging citizens in the way you just described.

We'll structure the next questions based on the research phases. Please have a look at this graph. It is a very simplified version of the scientific research process. There might be tasks missing. Please let us know if this is the case or if there is anything that is unclear to you.

Conceptual phase	**Design and planning phase**	**Empirical phase**	**Analysis and writing phase**	**Dissemination phase**
Formulating the research problem Determining the research purpose Defining the research question	Selecting a research design Developing study procedures and materials Determining the sampling and data collection plan Acquiring funding	Sampling data Collecting data Processing data for analysis	Analyzing data Interpreting results Writing the report	Communicating/publishing results

Main questions I:

3. Which tasks [are / were] performed by citizens in which phase and how?

4. Please let us know why / why not you involved citizens in each phase?

Follow-up questions I:

- *[Ask again if interviewee did not explain all phases]*: Why did you / why did you not involve citizens in the [name specific phase]?
- In which tasks is it particularly difficult to involve citizens? Why?

Main question II:

5. Which decisions [do / have] you share(d) with citizens in which phase? Please let us know why / why not?

   Standardized explanation: By decision-making we mean the process of choosing among several alternative possibilities. Every decision-making process produces a final decision, which may or may not prompt an action.

Auxiliary questions:

- [Do / have] you share(d) decisions with citizens in the research phases? Why / why not?

  Standardized explanations:

  - In the conceptual phase this could be selecting the research problem or research question.
  - In the design and planning phase this could be selecting the research design or sampling strategy.
  - In the empirical phase this could be selecting the data collection procedure or subjects for a qualitative study.
  - In the analysis and writing phase this could be selecting analytical methods for data analysis and interpretation or methods to review existing literature on the study topic.
  - In the dissemination phase this could be selecting the medium on which findings should be published, and individuals who should receive authorship for the study results.

Follow-up questions II:

- How are decision rights shared with citizens?
- Which decisions are particularly difficult to share with citizens? Why?

Part 4: Experienced and expected barriers to advancing to or conducting co-created citizen science (inductive-deductive approach)

Introduction sentence: In the next part of the interview, we’d like to talk about so-called co-created citizen science projects.

Standardized explanation: We mean projects in which researchers and citizens share decision rights in an equal partnership throughout all research phases. As these projects are uncommon in research, we’d like to understand under which circumstances such projects make sense and don’t make sense.

Main questions for researchers who <u>have not conducted</u> co-created projects:

6. What do you think about the usefulness and / or applicability of co-created projects?
7. When you think of the conceptualization of your project, did you consider engaging citizens more deeply (i.e. involving citizens in more tasks or sharing more decisions with them or both)?

Follow-up questions I:

- What do you think would have helped you to engage citizens more deeply (i.e. involving citizens in more tasks or sharing more decisions with them or both)? Why?
- From your experience, what are the barriers / challenges / obstacles / difficulties related to engaging citizens more deeply (i.e. involving citizens in more tasks or sharing more decisions with them, or both)?

Main questions for researchers who <u>have conducted</u> co-created projects:

6. What do you think about the usefulness and / or applicability of co-created projects?
7. From your experience, what are the barriers / challenges / obstacles / difficulties related to co-creation (i.e. projects in which researchers and citizens share decision rights in an <u>equal partnership</u> throughout <u>all</u> research phases)?

Follow-up questions II on the individual level:

- *[Inductive]:* Did you experience any constraints on the individual level? Which constraints and why?

  Standardized explanation: The individual level comprises the smallest unit of analysis and includes aspects that can be attributed to an individual person such as one's values and beliefs.
- *[Deductive]:* Based on your experience, do some researchers lack certain skills to [engage citizens more deeply / co-create]? Is a lack of certain skills of researchers a barrier to [engage citizens more deeply / co-create]? Which skills and why?
- *[Deductive]:* Based on your experience, is it more difficult to conduct citizen science if you have a certain seniority level (e.g. full professor vs. PhD student)? Is having a certain seniority a barrier to [engage citizens more deeply/ co-create]? Which seniority levels and why?
- *[Deductive]:* Based on your experience, do some citizens lack certain skills to [be engaged more deeply / co-create]? Is a lack of certain skills of citizens a barrier to [engage citizens more deeply / co-create]? Which skills and why?

Follow-up questions II on the project level:

- *[Inductive]:* Did you experience any constraints on the project level? Which constraints and why?

  Standardized explanation: The project level represents a structural aggregation of individuals and includes aspects that can be attributed to the project in which the individual is positioned. An example is the project's mission.

- *[Deductive]:* Based on your experience, is it more difficult to conduct [deeper forms of / co-created] citizen science for some project types than others? Are certain project types a barrier to [engage citizens more deeply / co-create]? Which project types and why?
- *[Deductive]:* Based on your experience, is it more difficult to conduct [deeper forms of / co-created] citizen science in some disciplines than others? Are certain disciplines a barrier to [engage citizens more deeply / co-create]? Which disciplines and why?

Follow-up questions II on the organizational level:

- *[Inductive]:* Did you experience any constraints on the organizational level? Which constraints and why?

  Standardized explanation: The organizational level represents a structural aggregation of individuals and includes aspects that can be attributed to the organization in which the individual is positioned. An example is the institution's (e.g. university's) mission.
- *[Deductive]:* Based on your experience, is it more or less difficult to conduct [deeper forms of / co-created] citizen science if you are employed by a certain university than another? Are there certain characteristics that create a barrier to [engage citizens more deeply / co-create]? Which characteristics and why?

  Standardized explanation: Characteristics could be the size, infrastructure, or resources, among other things

Follow-up question II on the ecosystem level:

- *[Inductive]:* Did you experience any constraints on the ecosystem level? Which constraints and why?

  Standardized explanation: The ecosystem level goes beyond an aggregation of individuals and includes the surrounding support system in which the individual person, the project, and the organization are embedded. The ecosystem level comprises, for example, of governmental regulations and societal norms.
- *[Deductive]:* Based on your experience, do you feel that some citizen science projects lack acceptance of relevant peers (i.e. fellow scientists)? Is lack of acceptance a barrier to [engage citizens more deeply / co-create]? Why?
- *[Deductive]:* Based on your experience, does the current science (incentive) system make it easier or more difficult to [involve citizens more deeply/ co-create]? Is the current science (incentive) system a barrier to [engage citizens more deeply / co-create]? Why?

Follow-up question III:

- You've already mentioned some barriers earlier during our conversation. Will some of them be different or stronger for co-created projects (in which researchers and citizens share decision rights in an <u>equal partnership</u> throughout <u>all</u> research phases) compared to citizen science projects in which citizens are involved in only few research phases and receive no or only few decision rights?

Part 5: Platform-based solutions

Introduction: We'd like to spend the last ten minutes of the interview on platform intermediaries.

Standardized explanation: We mean the various online intermediaries that act as a link between researchers and citizens. You may know Zooniverse, the citizen science platform that hosts and lists projects, or Amazon MTurk, the labor market platform.

Main question:

7. Have you used a platform intermediary to engage citizens into the [project name] or into another research project? Why this particular platform?

If yes:

8. How did you become aware of the platform? Did you check different platforms?
9. Which features of the platform do you find most helpful and least helpful? Why?
10. How has the platform influenced the project or the level of engagement of citizens in this project?
11. Has the platform helped you overcome any of the mentioned challenges in [project]? How?

If not:

15. Now, let's talk about platform intermediaries. Why did you conduct your project without a platform?
16. Did you check different platforms before deciding not to use a platform?

Follow-up questions:

- How should a platform's products or services or features be designed to best support scientists who want to engage citizens throughout all research phases as an equal partner, sharing decisions with them?
- Where do you think are the limits of platform intermediaries? Are there any issues that they cannot help with and you could better solve another way (e.g. offline through discussions, etc.)?
- I see. Could you elaborate on why you think that?
- Interesting. What would be a better solution?

Ending the interview

Main question:

17. Is there anything else you would like to tell us about involving citizens in research that we did not talk about yet?

If the interviewee has no further points to add, the authors offer to answer remaining questions from the interviewee, then say thank you and goodbye.

<u>Vocabulary (standardized explanations):</u>

- **Citizen science:** This refers to the voluntary and intended engagement of citizens (commonly referred to as "non-scientists", the "crowd", "citizen scientists", "amateur scientists", "volunteers", the "public" or the "general population") into the scientific research process.
- **Research phases:** Please have a look at this graph. It is a very simplified version of the scientific research process. There might be tasks missing. Please let us know if this is the case or if there is anything that is unclear to you.

Conceptual phase	Design and planning phase	Empirical phase	Analysis and writing phase	Dissemination phase
Formulating the research problem Determining the research purpose Defining the research question	Selecting a research design Developing study procedures and materials Determining the sampling and data collection plan Acquiring funding	Sampling data Collecting data Processing data for analysis	Analyzing data Interpreting results Writing the report	Communicating/publishing results

- **Engagement / Involvement / Participation:** We mean that citizens actively contribute to the research project by using their cognitive abilities and/or knowledge assets. They complete tasks in one or many phases of the research project, for example in the empirical or conceptual phase. This goes beyond citizens being merely informed or consulted.
- **Decision-making:** By decision-making we mean the process of choosing among several alternative possibilities. Every decision-making process produces a final decision, which may or may not prompt an action.
- **Contributory (classic) citizen science:** We mean projects in which citizens do not receive any decision rights and in which they are involved in only few research phases. Most current projects, which usually limit public involvement to simple data collection, coding, processing, or analysis tasks, fall into this category.
- **Co-created citizen science:** We mean projects in which researchers and citizens share decision rights in an equal partnership throughout all research phases. Only few current projects fall into this category, as only few researchers involve citizens in the formulation of a research question, the development of a research design, or the study dissemination phase.
- **Barriers / challenges / obstacles / difficulties:** This can be anything that prevents the researcher from involving citizens in more phases and giving citizens more decision rights. It can be something that the researcher can influence or something that the researcher cannot influence easily. One might think of internal barriers linked to researcher's capabilities or external constraints, for example the context or situation the researcher is in, the resources that he / she has outside the team, the people around him / her, etc.
- **Online platform intermediary:** We mean the various online intermediaries that act as a link between researchers and citizens. You may know Zooniverse, the citizen science platform that hosts and lists projects, or Amazon MTurk, the labor market platform.
- **Multilevel analysis (individual, project, organizational, ecosystem level):**

- The individual level comprises the smallest unit of analysis and includes aspects that can be attributed to an individual person such as one's values and beliefs.
- The project level represents a structural aggregation of individuals and includes aspects that can be attributed to the project in which the individual is positioned. An example is the project's mission.
- The organizational level represents a structural aggregation of individuals and includes aspects that can be attributed to the organization in which the individual is positioned. An example is the institution's (e.g. university's) mission.
- The ecosystem level goes beyond an aggregation of individuals and includes the surrounding support system in which the individual person, the project, and the organization are embedded. The ecosystem level comprises, for example, of governmental regulations and societal norms.

C) Interview guide for bespoke platform stakeholders

A note about the interview guide

This is a flexible interview guide for conducting semi-structured interviews. The order of and the specific questions asked will vary, and additional questions may be asked, and some may be omitted. Adjustments will be made by considering the participants' context and the flow of the conversation. The interview guide will not be sent to the interviewees beforehand to avoid potential bias in interviewee's responses. If an interviewee requests the questionnaire prior to the interview, only selected main questions will be sent.

Interview questions

Opening the interview

The authors briefly introduce themselves and the research field (i.e. citizen science and how it is applied in science). They remind the interviewee about his/her written consent (i.e. email confirmation) to record the interview and to use the input for the underlying study.

The authors walk the interviewee through the interview structure, telling them that questions about their experience with citizen science and with the specific platform are asked.

Part 1: Reference data and context of the interviewee

Introduction sentence: Before we start with the interview, we would like to get to know you better.

Main questions:

2. As a [position], what would you say are your main tasks? And very briefly in one or two sentences, what is your main research interest? What is your role in the [project]?

Part 2: General information on the citizen science project

Introduction sentence: Now, we are interested in learning about the citizen science project [name] that you [did / are doing] on [platform, if applicable].

Main question [the authors briefly summarize the citizen science project]:

2. Could you please give us a brief summary about the research project?

Follow-up questions:

15. Which tasks [are / were] performed by citizens? Please let us know why you decided to involve citizens in this way.
16. Which decisions [do / have] you share(d) with citizens? Please let us know why you decided to do this.

Part 3: Choosing an independent platform

Introduction sentence: We have seen that you have set up your own project website and/or platform. We'd like to speak a little bit about that now.

Main questions I [General information about the platform]:

17. What is the purpose of the platform?
18. Could you please describe the platform? What are its main features?

Follow-up questions:

19. Why did you decide to include these features? Why do you find these features helpful / important to have on a platform?
20. How or through which features does [platform] help you to involve citizens in particular research tasks?
21. How or through which features does [platform] help you to engage citizens in particular research decisions?

    Standardized explanation: By decision-making we mean the process of choosing among several alternative possibilities. Every decision-making process produces a final decision, which may or may not prompt action.

Main questions II [Choosing an independent platform]:

22. Why did you conduct your project with your own platform?
23. Did you check different platforms before deciding not to use another platform such as the Zooniverse?

Follow-up questions:

24. Did you decide to set up your own platform due to limits of existing platforms on the market? What are existing solutions missing?

Part 4: Barriers to co-creation

Introduction sentence: In the next part of the interview, we'd like to talk about so-called co-created citizen science projects.

Standardized explanation: We mean projects in which researchers and citizens share decision rights in an equal partnership throughout all research phases. As these projects are uncommon in research, we'd like to understand under which circumstances such projects make sense and don't make sense.

Main questions I [Barriers to co-creation]

25. What do you think about the usefulness and / or applicability of co-created projects?
26. When you think of the conceptualization of your project, did you consider engaging citizens more deeply (i.e. involving citizens in more tasks or sharing more decisions with them or both)?
27. From your experience, what are the barriers / challenges / obstacles / difficulties related to co-creation (i.e. projects in which researchers and citizens share decision rights in an equal partnership throughout all research phases)?

Part 5: Platform-based solutions for co-creation

Main questions I:

28. **How should a platform's products or services or features be designed to best support** scientists who want to engage citizens throughout all research phases as an equal partner, sharing decisions with them?

Introduction sentence:

In the last 15 minutes of the interview, we'd like to ask some specific questions about how your platform helps researchers engage citizens more deeply or co-create with them. From our interviews with researchers we know that researchers face certain challenges when wanting to co-create with citizens.

We'll show you these barriers, and would like to know if you agree or disagree with the statement, and then, if your platform offers any solutions to this problem and if so, which ones? You can also indicate if you can think of a solution to this problem.

So, let's start with the first barrier that researchers face.

3. *[Ask the following question, inserting the barriers a) through k)]*

   We know that [insert barrier a) through k) here]. This presents a barrier to engaging citizens more deeply in research. Does your platform offer any solutions to this problem? Which ones?

Individual level barriers:

l) ...some researchers struggle to gain **enough skilled participants** for their citizen science project, and especially maintaining them in the long-term
m) ...some **researchers lack certain skills**, e.g. communications skills, to engage with citizens more deeply
n) …some researchers with **certain seniority levels** (e.g. full professor vs. PhD student) find it more difficult to engage with citizens more deeply

Project level barriers:

o) ...some researchers have **methodological concerns**, e.g. with regards to ensuring the validity of data collected by citizens
p) ...some researchers face **issues with regards to data security and privacy** in citizen science projects
q) ...some researchers do **not want to share data or intermediary results openly** with a broad community

r) ...some researchers find it challenging to engage citizens more deeply or meaningfully in **certain project types**, e.g. those projects that engage a large number of citizens worldwide, compared to others

Organizational level barriers:

s) …some researchers do not receive **sufficient support and / or resources** (e.g. funding) from their research institutions

Ecosystem level barriers:

t) ...some researchers find that there exists a **lack of knowledge of citizen science** as a field, and a **lack of best practices** of conducting citizen science projects, especially those that engage citizens more deeply
u) ...some researchers who engage citizens in science **lack acceptance from peers** (i.e. fellow researchers)
v) …some researchers find that the **external environment**, e.g. the scientific community or government, does **not sufficiently support** citizen science especially at deeper citizen engagement levels (e.g., researchers have difficulties when publishing their citizen science work in peer-reviewed journals)

Ending the interview

Main question:

4. Is there anything else you would like to tell us about the role or function of platforms in citizen science that we did not talk about yet?

<u>Vocabulary (standardized explanations):</u>

- **Citizen science:** This refers to the voluntary and intended engagement of citizens (commonly referred to as "non-scientists", the "crowd", "citizen scientists", "amateur scientists", "volunteers", the "public" or the "general population") into the scientific research process.
- **Research phases:** Please have a look at this graph. It is a very simplified version of the scientific research process. There might be tasks missing. Please let us know if this is the case or if there is anything that is unclear to you.

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- **Engagement / Involvement / Participation:** We mean that citizens actively contribute to the research project by using their cognitive abilities and/or knowledge assets. They complete tasks in one or many phases of the research project, for example in the empirical or conceptual phase. This goes beyond citizens being merely informed or consulted.

- **Decision-making:** By decision-making we mean the process of choosing among several alternative possibilities. Every decision-making process produces a final decision, which may or may not prompt an action.
- **Contributory (classic) citizen science:** We mean projects in which citizens do not receive any decision rights and in which they are involved in only few research phases. Most current projects, which usually limit public involvement to simple data collection, coding, processing, or analysis tasks, fall into this category.
- **Co-created citizen science:** We mean projects in which researchers and citizens share decision rights in an equal partnership throughout all research phases. Only few current projects fall into this category, as only few researchers involve citizens in the formulation of a research question, the development of a research design, or the study dissemination phase.
- **Barriers / challenges / obstacles / difficulties:** This can be anything that prevents the researcher from involving citizens in more phases and giving citizens more decision rights. It can be something that the researcher can influence or something that the researcher cannot influence easily. One might think of internal barriers linked to researcher's capabilities or external constraints, for example the context or situation the researcher is in, the resources that he / she has outside the team, the people around him / her, etc.
- **Online platform intermediary:** We mean the various online intermediaries that act as a link between researchers and citizens. You may know Zooniverse, the citizen science platform that hosts and lists projects, or Amazon MTurk, the labor market platform.
- **Multilevel analysis (individual, project, organizational, ecosystem level):**
    - The individual level comprises the smallest unit of analysis and includes aspects that can be attributed to an individual person such as one's values and beliefs.
    - The project level represents a structural aggregation of individuals and includes aspects that can be attributed to the project in which the individual is positioned. An example is the project's mission.
    - The organizational level represents a structural aggregation of individuals and includes aspects that can be attributed to the organization in which the individual is positioned. An example is the institution's (e.g. university's) mission.
    - The ecosystem level goes beyond an aggregation of individuals and includes the surrounding support system in which the individual person, the project, and the organization are embedded. The ecosystem level comprises, for example, of governmental regulations and societal norms.

9.4 Transcription rules

A clean verbatim transcription style based on Poland (2011) was applied in this thesis. The following transcription style (rules) were used.

1. The interview is transcribed word by word using U.S. American English spelling. The content (i.e. words spoken) and the meaning is not altered. This means that the transcriber does not add any new words or phrases him-/herself to the transcript (even if those would make the sentence more understandable).
2. Undecipherable words: When a word is acoustically not understandable, the transcriber indicates this by [inaudible minute: seconds], e.g. [inaudible 03:44].
3. If the transcriber is not sure if he / she understood something correctly, he / she puts the word in brackets, highlighting the time of the word, i.e. [word minute: seconds]. For example, the transcriber is not sure if the speaker said “That sounds harsh” or “That sounds hard”, but the transcriber thinks that the speaker said “harsh”, then write down “That sounds [harsh 10:12]”.
4. Simultaneous speech: If one speaker interrupts the other in mid-sentence, but the first speaker completes his or her thought, that sentence is first finished in the transcript.
5. EM dashes: Dashes should be used to offset parenthetical expressions, such as an aside or remark interjected by the speaker. For example: “The initial - how can I say it your terms? - formulating the research problem and determining the research purpose, that was clearly led by researchers.
6. Numbers / signs: Whole numbers from one through ninety-nine are spelled out in ordinary text, as are any of these numbers followed by the words “hundred,” “thousand,” and “million.” Percentages and currencies are spelled out word by word.
7. The transcriber does not remove any words that add context or meaning. However, meaningless word fractions, only as mentioned below (see a) - e)) are removed by the transcriber. When in doubt whether something adds meaning or not, everything being said is transcribed word by word.
    i) Stutters or stumbles or repetitive instances of words should be removed. For example, “I think, I think” is transcribed as “I think”, and “I, I, I” is transcribed as “I”.
    ii) Filler speech, including "um", "uh", etc. should be removed. For example, "uhm, I don't know" is transcribed as "I don't know")
    iii) In most instances, non-speech sounds (e.g. coughing and throat cleaning) should be removed. For example: "And he said [Speaker 1 coughing] that it's ok" is transcribed as "And he said that it's ok". However, non-speech sounds that add meaning to the content are included. Examples are laughing or other emotional sounds of any interview participant. In these cases, brackets are used to describe the way something is said or the reaction of the listener, such as [Laughing]. The first letter of the word is capitalized, and there are spaces before and after the brackets. If possible, and if appropriate, the transcriber avoids interrupting the text until after the speaker’s sentence is complete. For example. "Okay, now you caught me [Laughing]".
    iv) Meaningless instances of words (e.g. “So” at the start of sentences, and “like” only when used as filler speech” are removed. For example: "So I've done this, so, as you see, this was not easy" is transcribed as "I've done this, as you see, this was not easy")

v) Conversational affirmations or interruptions by the interviewer that are reassuring remarks, while the interviewee is telling a story, are removed. For example: Speaker 1: "It's complicated."; Speaker 2: "Hmmh yeah, I see." Speaker 1: "It all started last year", Speaker 2: "Could you tell me more about that?" is transcribed as Speaker 1: "It's complicated. It all started last year", Speaker 2: "Could you tell me more about that?")

vi) In most instances, pauses in speech are not transcribed. For example, when the interviewee makes natural pauses during a sentence, e.g. “I [short pause] have experienced this in my team” is transcribed as “I have experienced this in my team.” However, if a pause adds meaning, it is transcribed. For example, if an interviewee makes a long pause before answering a question because he / she does not know what to answer, the pause is transcribed. Pauses are transcribed as ellipses in parentheses. For example: “Um, uh [pause]. I don’t know” is transcribed as “(…) I don’t know.”

9.5 Pilot testing

For the piloting of the interview guide on the barriers to co-created citizen science, two trial runs were performed. The initial interview guide included questions to obtain reference data, the context on the interviewee, general information on the citizen science project, the choice of the scope of the current engagement of citizens in the project, the interviewees' attitude towards co-created citizen science, experienced and expected barriers to transitioning to co-created citizen science, and platform-based solutions. For reasons of ease, convenience sampling was applied to select interviewees (Thornhill et al., 2009). The initial test was performed with a researcher from the personal network of the authors. The interviewee represented an "A" case (i.e. a contributory citizen science project) as explained earlier. The interview was conducted in person. One author asked the questions following the interview guide while the other took notes to be able to suggest improvements. The interview was audio recorded upon permission for later review. After the interview, the interviewee was asked for feedback which helped to evaluate the clarity of questions and to identify questions that made the interviewee uncomfortable, among other things.

A second test was conducted analogously to the first with a researcher who accepted the request for an interview first. Again, the interviewee represented an "A" case. From the interview, the authors learned that the interview guide contained too many questions; they had difficulties to ask all within the ninety-minute timeframe of the interview. As a result, the number of questions was reduced. For example, fewer questions to obtain reference data were included so that the interviewers could ask questions related to the citizen engagement at an earlier point in time. A further change included adding questions to the end of the interview guide that particularly addressed the barriers the authors had identified in their literature search. This represents the deductive approach in the research project.

As a final step, feedback was collected from the thesis supervisors who commented on the suitability of the questions. As a result, some remaining redundancies in the interview guide were removed, the structure adjusted in parts (e.g. asking for problems earlier in the interview), and definitions for undefined terms (e.g. decision-making) were added. For the piloting of the interview guide on the platform solutions, one trial run was performed. The structure of the initial interview guide included questions to obtain reference data, the context of the interviewee, information on the platform's purpose and functions in general as well as in the specific context of citizen science, and lastly, its benefits and limitations on solving barriers to co-created citizen science.

Prior to the pilot interview, the authors received feedback from the thesis supervisors. Based on their recommendation, the authors established matching points between the interview guides on barriers to co-creation and platform solutions (i.e. having the overlapping questions in both interview guides) to ensure greater comparability of the collected data. Due to the prevalence of existing project listing platforms, the initial test was performed with a project manager affiliated to a project listing platform. Similarly, to the setup of the pilot interview on barriers to co-creation, a main interviewer followed the questions of the interview guide while the teammate took notes for improvements. The result of the pretest was positive in that the structure and questions of the interview guide on platform solutions was largely maintained. Only minor parts were shortened by merging similar questions. Further, the wording of some questions was rephrased to avoid potential misunderstandings. As the data collected in the pilot and subsequent interviews authors was comparative, the authors decided to include the pilot interview candidate into their sample.

9.6 Framework of factors that make up transition barriers to co-created citizen science

Green = Barrier from literature confirmed, Blue = New barrier identified in empirical study, Orange = Barrier from literature not confirmed, Pink = New factor, theoretical saturation not reached, Purple = Theoretical saturation not reached, Grey = No data obtained

Level	Factors that make up the barriers in (co-created) citizen science
Individual (researcher)	***Insufficient knowledge and skills (R4, R5, R6, R7)***
	Leadership and interpersonal skills (R4)
	Communication skills (R4)
	Mediation, consensus building, diplomacy (R4)
	Listening skills (R4)
	Characteristics
	Seniority (R2, R3, R12, R13)
	Insufficient resources
	Time, i.e. limited capacity and mismatches in schedules (R12)
	Perceptions, attitudes, beliefs, values, etc.
	Ivory tower mentality (R9)
	Reluctance to share control and give up power (R1)
	Fear of uncertainty & reluctance to change (R1)
	Experiencing insecurities (e.g. lack of confidence in designing project) (R4)
	Distrust of citizens contributions (quality concerns & lack of quality assurance) (R3)
	Motive to conduct citizen science (non-social motives) (R1, R8)
	Perception on the usefulness & applicability of co-created citizen science (R1)
	Individual career opportunities (R2)
	Expected lack of citizen engagement (R7)
	Expected issues in goal alignment (R8)
	Willingness to spend efforts on non-research related tasks (R12)
	Dedication (e.g. unwillingness to do unpaid work (R13)
Individual (Citizen)	***Insufficient knowledge and skills***
	Low education level (R5, R6)
	Insufficient scientific literacy (R5)
	Insufficient domain knowledge (R5)
	Insufficient resources
	Time (R7)
	Characteristics and demographics

	Geographic location
	Health status (R6)
	Age (elderly) (R6)
	Age (children) (R6)
	Perceptions, attitudes, beliefs, values, etc.
	Lack of confidence in one's knowledge assets (R7)
	Lack of (sustained) motivation
	Interest spread among different citizen groups (i.e. few very interested participants) (R7)
	Lack of interest in certain research fields (R7, R8)
	Diminishing interest over time (R7)
	Addressing the wrong motivational drivers
Project and group (team)	***Research project characteristics***
	Unsuitable research study and discipline (R1, R2, R4, R5, R6, R7, R9, R1)
	Research driven projects (R1, R2, R3, R7, R8, R13)
	Discipline (R1, R2, R4, R5, R6, R7, R9, R16)
	Large scale projects (R7, R11)
	Online projects (R6, R10, R11, R14)
	Short term projects (R5, R6, R7, R9, R13)
	School projects (R6)
	Project set-up
	Governance structure (hierarchical)
	Project coordination
	Task design (R4)
	Task allocation (R4)
	Structuring teamwork
	Group level interactions
	Challenges in group alignment in interdisciplinary teams (R8 – R10)
	Diverging interests (R8)
	Lack of mutual trust and respect (e.g. due to skepticism) (R9)
	Missing team spirit (R10)
	Challenges in coordination & decision-making with a large crowd (see also project type) (R10)
	Resource and infrastructure constraints
C r a	Resource constraints (e.g. human resources) (R15)

	Inadequate infrastructure (e.g. technology) (R15)
	Remote geographic location (R15)
	Choice restrictions (e.g. technology choice) (R15)
	Strategy and mission
	Unaligned mission (R15)
	Traditional science system
Ecosystem (external environment)	Little reward for citizen science activities (R1)
	Discouragement of sharing of intermediate results (R11)
	Project culture focused on gaining efficiency
	Lack of acceptance from the scientific community
	Quality concerns of the community (R2)
	Challenges to publish in peer-reviewed journals (R2)
	Lack of knowledge and best practices
	Lack of knowledge and best practices on co-creating research (R4)
	Insufficient (financial) support from funding agencies
	Inflexible traditional funding schemes (R13)
	Insufficient funding schemes for citizen science (R13)
	Too low funding amounts and too short funding durations (R13)
	Misaligned structure (timing) of funding (R13)
	Governmental policies, regulations, and laws
	Legal and ethical concerns, i.e. data privacy & protection (R14)
	Legal and ethical concerns related to handling human (e.g. health) data (R14)
	Lack of knowledge among external environment
	Lack of knowledge of citizen science in the external environment (R17)
	Insufficient political and government support
	Insufficient political and governmental support (R18)

9.7 Participant interview consent form

Participant interview consent form

Thank you for your interest in participating in an interview for our study on citizen science and its application in research.
The interview duration and location is based on previously agreed terms through mail or phone conversations. To participate, please complete and sign the brief form below.

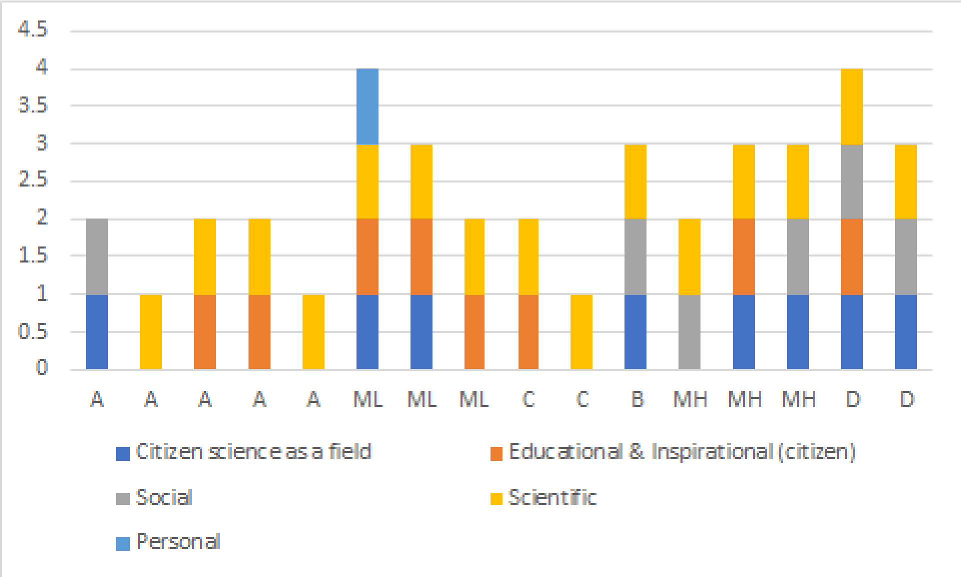
Please tick the boxes below to confirm that you agree with each statement:

I understand that my participation is voluntary and that I am free to withdraw at any time prior or during the interview without giving any reason. In addition, should I not wish to answer any particular question or questions, I am free to decline.	☐
I understand that my responses will be kept strictly confidential. I understand that my name will not be linked with the research materials and will not be identified or identifiable in the report or reports that result from the research.	☐
I agree that I do not share interview questions and any content discussed in the interview, which reveals the study focus, with those who have not been part of the interview, as this might lead to potential biases in their future participation.	☐
I agree for this interview to be audio-recorded. I understand that the audio recording made of this interview will be used only for analysis. I understand that no other use will be made of the recording without my written permission, and that no one outside the research team will be allowed to access the original recording.	☐
I agree to take part in this interview.	☐

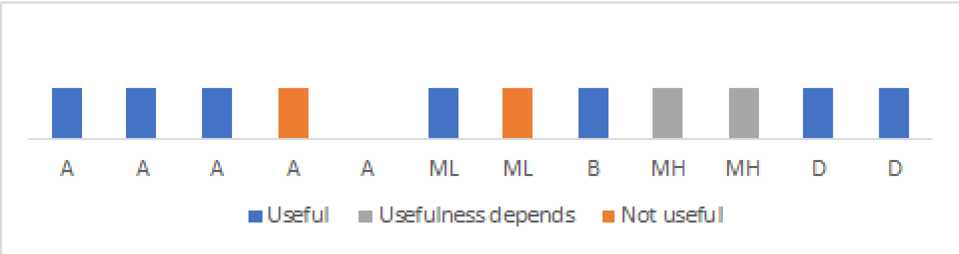
If you have questions about this study, please contact: Alissa Prinsloo (alpr17ac@student.cbs.dk) or Tanja Krasnikov (takr17ab@student.cbs.dk).

______________________	______________	________________
Name of participant	Date	Signature

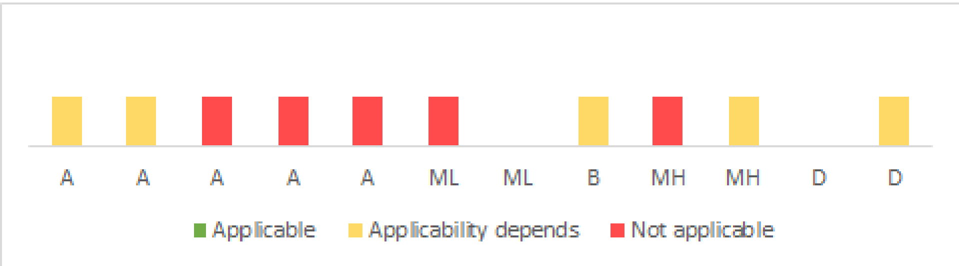
9.8 Graphs referenced to in section 6.1 Barrier R1



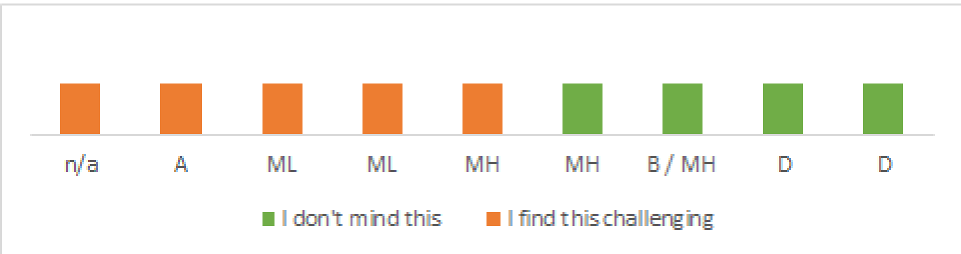
Barrier R1: Reasons for conducting CS



Barrier R1: Responses about the usefulness of co-creation



Barrier R1: Responses on the applicability of co-creation



Barrier R1: Attitude towards uncertainty and change

9.9 Influencing variable referenced in Chapter 5 : Discipline

The analysis shows that co-creation projects are more difficult in some disciplines than others due to differences in a) acceptance of CS among the disciplines' scientific community, b) a lack of knowledge and best practices for CS in the field, c) legal barriers, d) barriers of ability of citizens, and e) a lack of engagement from citizens. The table below shows that researchers in the life sciences (medicine) face the greatest while those in the life sciences (biology) face the least issues.

Challenges in disciplines	Low acceptance of CS	Lack of knowledge & best practices	Legal barriers	Barriers of ability of citizens	Lack of engagement from citizens
Humanities & Social Sciences (Social & behavioral sciences)	yes (1)	yes (1)	n/a	n/a	n/a
Humanities & Social Sciences (Humanities)	yes (2)	yes (2)	n/a	no (1)	yes (for basic research) (2)
Natural sciences (Physics)	no (1)	n/a	yes, online (1)	yes (1)	no (1)
Life Sciences (Medicine)	yes (1)	yes (2)	yes (2)	yes (health, 1)	yes (2)
Life Sciences (Biology)	no, acceptance growing (1)	no (1)	no (1)	n/a	yes (for basic research) (1)

9.10 Glossary

- **Project hosting platforms** facilitate the creation and management of CS projects. Often abbreviated to "hosting" platforms.

Key interaction	Distinct or core functions
Direct interaction between interested contributors (e.g. citizens) and project initiators (e.g. researchers) that make use of the contributions (i.e. two- or multi-sided platform)	Combination, comprised of 1) an existing crowd or community on the platform, 2) tools enabling group interaction and coordination and 3) the capability to crowdsource the collection, processing or analysis of large data volumes.

Table - Summary of characteristics of project hosting platforms

- **Project Listing platforms** promote projects within the CS community as well as to potential interested-parties. Often abbreviated to “listing” platforms.

Key interaction	Distinct or core functions
Direct interaction among researchers (i.e. network), and between researchers as project initiators and citizens as interested contributors (i.e. two- or multi-sided platform)	Service, including 1) an existing crowd on the platform, 2) tools facilitating public outreach and science communication, 3) a network of researchers and partners to leverage and exchange knowledge on citizen science

Table - Summary of characteristics of project listing platforms

- **Labor Market platforms** help researchers outsource defined tasks to a crowd or (specialized) individuals against payment. Often abbreviated to *“labor*” platforms.

Key interaction	Distinct or core functions
Direct interaction between citizens (i.e. freelancers) as task fulfillers and researchers as crowdsourcers who make use of citizens contributions (i.e. two- or multi-sided platform)	Service, including 1) an existing crowd or community on the platform, 2) outsource research or non-research related tasks, 3) task coordination (mainly by matching citizen’s skill to the task)

Table - Summary of characteristics of labor market platforms

- **Crowdsourcing (contest) platforms** help researchers to systematically process solutions for idea generation and / or issue resolution, improving consensus building and coordination. Often abbreviated to “*crowdsourcing*” platforms.
- **Product Service platforms** offer to develop, provide and maintain a (standardized) technical infrastructure for CS projects. Often abbreviated to “*service*” platforms.

Key interaction	Distinct or core functions

Technological infrastructure is shared between researchers or citizens (i.e. technical users and beneficiaries alike), and can be customized by either party (i.e. product platform)	Service, including 1) design, development and maintenance of a technical system, 2) customization of features or system, 3) built-in standardized work flows

Table - Summary of characteristics of product service platforms

- **Community engagement platforms** help users to communicate, share and exchange information among group members. Often abbreviated to "*engagement*" platforms.
- **Citizen science (CS)** refers to the voluntary and intended engagement of citizens (commonly referred to as "non-scientists", the "crowd", "citizen scientists", "amateur scientists", "volunteers", the "public" or the "general population") into the scientific research process, Often abbreviated to "CS".
- **Engagement / Involvement / Participation** refers to when citizens actively contribute to the research project by using their cognitive abilities and/or knowledge assets. They complete tasks in one or many phases of the research project, for example in the empirical or conceptual phase. This goes beyond citizens being merely informed or consulted.
- **Decision-making:** By decision-making we mean the process of choosing among several alternative possibilities. Every decision-making process produces a final decision, which may or may not prompt an action.
- **Contributory (classic) CS:** We mean projects in which citizens do not receive any decision rights and in which they are involved in only few research phases. Most current projects, which usually limit public involvement to simple data collection, coding, processing, or analysis tasks, fall into this category.
- **Co-created CS:** We mean projects in which researchers and citizens share decision rights in an equal partnership throughout all research phases. Only few current projects fall into this category, as only few researchers involve citizens in the formulation of a research question, the development of a research design, or the study dissemination phase. Often referred to as "co-creation".
- **Barriers / challenges / obstacles / difficulties:** This can be anything that prevents the researcher from involving citizens in more phases and giving citizens more decision rights. It can be something that the researcher can influence or something that the researcher cannot influence easily. One might think of internal barriers linked to researcher's capabilities or external constraints, for example the context or situation the researcher is in, the resources that he / she has outside the team, the people around him / her, etc.
- **Online platform intermediary:** We mean the various online intermediaries that act as a link

between researchers and citizens. You may know Zooniverse, the CS platform that hosts and lists projects, or Amazon MTurk, the labor market platform. Often referred to as "platform".

- **Multilevel analysis (individual, project, organizational, ecosystem level):**
    - The individual level comprises the smallest unit of analysis and includes aspects that can be attributed to an individual person such as one's values and beliefs.
    - The project level represents a structural aggregation of individuals and includes aspects that can be attributed to the project in which the individual is positioned. An example is the project's mission.
    - The organizational level represents a structural aggregation of individuals and includes aspects that can be attributed to the organization in which the individual is positioned. An example is the institution's (e.g. university's) mission.
    - The ecosystem level goes beyond an aggregation of individuals and includes the surrounding support system in which the individual person, the project, and the organization are embedded. The ecosystem level comprises, for example, of governmental regulations and societal norms.