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11. The transdisciplinary potential of citizen science

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INTRODUCTION

This chapter considers the transdisciplinary potential of citizen science. We interpret transdisciplinarity as the practices of citizen science that move beyond scientific norms and social conventions. We draw a comparison between the integration of knowledge and the integration of people in science. Throughout this chapter, we suggest that citizen science can be transdisciplinary, but it is not automatically so. It needs to challenge the boundaries of disciplinary domains and the social order between professional and non-professional scientists. This distinction is more clearly set out and discussed in our framework for understanding the transdisciplinary potential of citizen science.

The fundamental ambiguity and uncertainty of citizen science, and the practices that are part of it, are important for our analysis of its transdisciplinary character. Citizen science can be, simultaneously, a tool that follows the very specific practices of a discipline, while also drawing on lessons about how public participation is based on experiential knowledge that does not belong to any specific discipline. Similarly, uncertainty is also part of the concept of transdisciplinarity, which is an emergent concept that is defined through many lenses, such as knowledge integration, understanding complexity, problem solving, trans-sectoral collaboration, or epistemology, since the 1970s (Klein, 2004; Le Moigne, 2007; UNESCO, 2016). A first step in this chapter is to present our shared understanding of transdisciplinarity and citizen science as a group of authors coming from different countries, disciplinary perspec- tives, and sectoral backgrounds.

This comparison between the integration of types of knowledge and the integration of groups of people in science enables us to shed some light on the common ground shared by transdisciplinarity and citizen science. Transdisciplinarity and citizen science can be generically understood as transformative practices of knowledge production. In other words, the innovative potential of transdisciplinarity and citizen science enables a higher level of integration of different types of knowledge and know-how. Both contribute to the same movement of accessing knowledge, often referring to open science or the democratisation of knowledge (Peters & Besley, 2019). These post-normal vectors involve an ethical dimension which recognises complexity between disciplines and solidarity between people in contrast to the dominant reductionist thought that inherently draws boundaries between both disciplines and people (Morin, 2008b, 2008a; Moustard & Leduc, 2020). In this way, our collective point of view on transdisciplinarity and citizen science relies on the transformative practices that consist of not only moving “across” and “between” the scientific standards but also “beyond”

them – as indicated by the Latin prefix *trans* (Nicolescu, 2002). For the purposes of this chapter, we draw a comparison between the integration of knowledge and the integration of people in science, and underline that citizen science has changed *who* is allowed to do things, but not *how* to do things. Essentially, methodologies and epistemologies used in citizen science activities in different disciplines are delimited by those discipline-based protocols in which the activity takes place. However, crucially, we argue that there is greater potential for transdisciplinarity in citizen science in terms of changes to the social and scientific practices of citizen science as collective action.

The core argument of this chapter interprets transdisciplinarity as the transformative practices of citizen science that move beyond scientific concepts, norms, and protocols. First, we present our understanding of transdisciplinarity and citizen science in this introduction; then we clarify our basic claim to transdisciplinarity in the following section. We compare the history of science and the sociology of science in order to highlight what transdisciplinarity and citizen science have in common. We then demonstrate how citizen science enables us to move beyond ready-made procedures, stereotyped approaches, and scientific standards. We focus on the practices of citizen science and their problem-solving potential as a distinctive kind of transdisciplinarity, and a framework of transdisciplinarity in citizen science. We describe two case studies: the first is the OpenCovid19 community that considers the Quantified Flu project as emblematic – both in terms of the highly diverse team of volunteer contributors within the project, but also in terms of the learning and knowledge produced through the transdisciplinary co-creation process and prototype implementation of the project results. The second case study focuses on the *Forschungsfall Nachtigall* – a citizen science project on nightingales in Berlin. It exemplifies our understanding of transdisciplinarity as transformative practice. Then, we reflect on the expectations of citizen science from policy that are inherently transdisciplinary. Funders at international and national levels are interested in citizen science for its potential to produce transdisciplinary benefits through its multiple objectives, scientific endeavours and engagements, and highly transdisciplinary outputs.

Finally, we present a common framework that will help explain the transdisciplinary nature of citizen science, by focussing on the challenges that citizen science projects seek to tackle. We describe the way project owners, be they scientists or other professionals, facilitate citizen science, independently of what the challenge is. Moreover, at the level of abstraction presented in Figure 11.2, it is necessary to generalise across areas of science and scholarship. In this sense, we are forced to view the scientific project as a problem-solving puzzle. The puzzle can be about the structure of the universe or the transcription of ancient papyri. By necessity, the specific project will be carried out within the epistemological, ontological, and methodological context of the discipline within which the knowledge is produced. Therefore, in a citizen science project, interpretive and qualitative approaches will be used, whereas an astronomy project will focus on very large datasets that can be analysed using astrophysical statistical techniques. As we analyse different forms of collaboration, it is possible to see how projects move from disciplinarity to transdisciplinarity, and from where the transdisciplinary potential emerges. This section also shows how moving away from mapping disciplines, to mapping the challenges themselves, removes disciplinary boundaries; and this is where citizen science thrives (Figure 11.2). If citizens are part of the collective endeavour of responding to multi-dimensional societal challenges effectively, disciplinary boundaries will be transgressed using citizen science, embracing a more inclusive approach both to citizens' different types of knowledge and expertise. To illustrate this approach in more detail, a third case study on

community food initiatives – at the Calthorpe Community Garden in London – is provided; it presents a situated, site-specific, field of community-led citizen science cultivated over many years. We conclude this chapter by revisiting our main argument that, as the field continues to develop, citizen science can move one step further towards transdisciplinarity, since this is where it truly has the potential to challenge the *status quo*.

PRACTICING CITIZEN SCIENCE – OUR MAIN CLAIM TO TRANSDISCIPLINARITY

At first glance, citizen science may seem simple. The term was introduced to the *Oxford English Dictionary* in 2014 and reads: "Scientific work undertaken by members of the general public often in collaboration with or under the direction of professional scientists and scientific institutions." Taking into consideration over 150 years of volunteers measuring weather conditions accurately (World Meteorological Organisation, 2001), or over 100 years of birds and other species' observations (e.g., Bonney, 1996), this seems appropriate. In these types of projects, people from all walks of life are involved in scientific work – frequently collecting data about nature – and sharing it with professional scientists who then carry out the analysis and interpret the results. The scientists also set the procedures for data collection, and therefore supervise the work. This definition might be an appropriate way to describe well-publicised novel forms of public participation in scientific research, such as Galaxy Zoo, in which tens of thousands of participants are using an online platform to help astrophysicists understand the development of the universe (Lintott et al., 2008). While the participants in the project do not actually collect any data, they do assist with analysis that helps to generate new understandings of data, with the supervision of scientists.

However, the burgeoning literature on citizen science suggests that almost all the elements of this definition are challenged; and studies suggest that some cases do not sit easily with these elements. Citizen science entails activities in the social sciences and humanities, and therefore it includes activities beyond "scientific work" (Causer et al., 2012; Albert et al., 2020). Concerning collaboration of and direction by scientists, citizen science projects include many community-led activities where the scientists are providing a supporting, rather than leading, role – and in some cases are not involved at all (Kimura & Kinchy, 2019). Moreover, another definition will not do better than the *Oxford English Dictionary*. Defining citizen science and its boundaries remains a challenge, and this is reflected in the literature – for example, in the proliferation of typologies and definitions (Haklay et al., 2021a) that exist to try to map the field of citizen science. Multiple vignettes from a recent study by Haklay et al. (2021b) illustrate the need to identify areas of agreement and disagreement within the citizen science community about what should be admitted as a citizen science activity. For example, a participant engaged in a project solely through the provision of financial support (what can be termed as "crowdfunding") is rarely considered a meaningful engagement to be recognised as citizen science. Elsewhere, a clinical trial using digital tools as part of the trial itself was characterised ambiguously as citizen science, especially if the digital tools were designed to support two-way communication. Cases in which scientists designed data collection activities and asked people to take part by carrying out a guided experiment were clearly recognised as citizen science. However, in all these cases, views and explanations were provided to support and oppose the extent to which a project constituted a citizen science activity. Notably, the

same study revealed common characteristics across the wide spectrum of citizen science activities, as well as many divergences.

Since the creation of modern universities, scientific knowledge has been increasingly organised according to disciplines that have grown in number continuously. However, this dominant story of burgeoning disciplines is indissociable from another story about the proliferation of disciplines. Numerous scholars have disrupted their disciplines and engendered new ones. In the contemporary history of biology, for example, the amateurism of Charles Darwin has resulted in a comprehensive understanding of the origins of species (Darwin, 1859). Elsewhere, Erwin Schrödinger (1944) has interrogated the emergence of life with the principles of physics. Then, after introducing the notion of chance in biological organisation, Jacques Monod (1971) contributed to founding the discipline of molecular biology. These examples illustrate the common attitude of the three scientists who were "ready to feel comfortable with uncertainty and not to be fearful of ignorance"; their open minds enabled them to go beyond mono-disciplinary structures of knowledge (UNESCO, 1998, p. 29). In other words, disciplinary boundaries can be counterbalanced by the integration of different aspects of segmented disciplines which feed into transdisciplinary practices. As Klein (2004) noted, transdisciplinarity is not a new discipline or super-discipline. It is akin to the science and art of discovering bridges between different areas of knowledge and different beings (Nicolescu, 2002). Klein (2004) also suggests that transdisciplinarity is an approach to research and problem solving that highlights the convergence of transdisciplinarity, complexity, and transsectorality in a unique set of problems that do not emanate from within science.

The history of disciplinary knowledge has been shaped by scholars who have conceived boundaries between academic and non-academic domains. The storyline of academic scholars working in proverbial ivory towers is challenged by the integration of non-academics and non-professionals into science, notably citizen science. For example, while his contemporary, Charles Darwin, was exploring remote islands, William Whewell, also recipient of the Royal Medal, searched for volunteers (including sailors, coastal surveyors, and amateur observers) to collect a million observations on ocean tides (Cooper, 2016). More recently, professional scientists have demonstrated how "non-literate" Indigenous people can produce reliable local knowledge (Moustard et al., 2021). Inclusive citizen science activities involve professional scientists "working to support others instead of focussing on their own projects" (Moustard et al., 2021, p. 2). Thus, the demarcation of science from non-science is continuously drawn and redrawn through inclusive practices of laypeople and lay-researchers.

Rigolot (2020) usefully reframes the debate on transdisciplinarity by considering it as a way of being – in this sense, as an ethical practice. In this chapter we frame citizen science as a transformative practice and therefore a specific and ethical way of being too. Transdisciplinary, community-based, interactive, or participatory research approaches are often suggested as appropriate means to meet both the requirements posed by real-world problems as well as the goals of sustainability science as a transformational scientific field (Lang et al., 2012). Debates about the different levels of participation in citizen science are also reflected in the discourse around citizen social science (Albert et al., 2020). However, the appearance of citizen science in the social sciences has led to more focus on Participatory Action Research, co-creation, and the transformative role of citizen science in terms of its impact on all those who participate. There is a form of inherent conservatism that is sometimes incorporated into citizen science; hence, it can be theoretically and epistemologically constrained. For example, the Zooniverse platform facilitates mainly a contributory role for participants, in that they can contribute

observations and data in a relatively restrained form of participation. This conforms to a safe disciplinarily approach, using accepted methodologies within conventional scientific research. Another example in ecology and the water sciences concerns increasing public involvement in monitoring water resources, climate variables, water quality, and in mapping and modelling exercises (Walker et al., 2021). Here, participants are asked to contribute data in a broadly conventional way in the natural sciences, leaving the more participatory approaches for others in the social sciences. For the purposes of this chapter, we emphasise that citizen science has changed *who* is allowed to do things, but not *how* to do things. By this we mean that the methodologies and epistemologies used in citizen science activities in different disciplines are delimited by the discipline-based protocols in which the activity takes place.

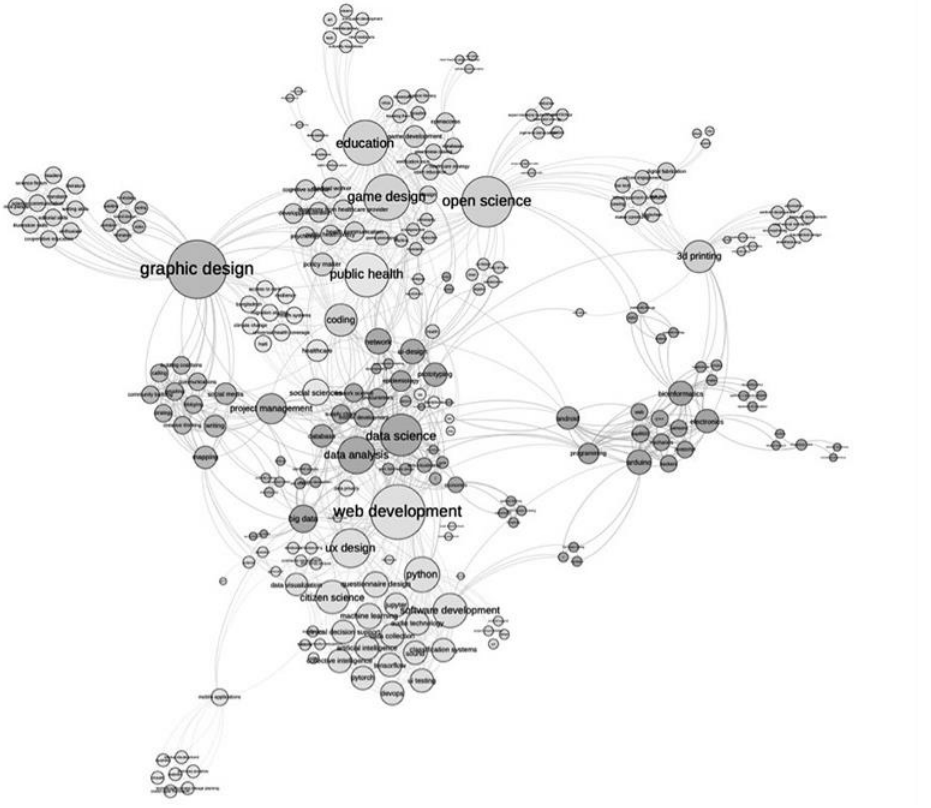
Citizen science is transdisciplinary when it involves transformative ethical practices that contribute simultaneously to disrupt disciplinary domains and social hierarchies between professional and non-professional scientists. Indeed, transdisciplinary innovation entails placing disciplinary interactions in an integrated system with a social purpose, notably continuously evolving and adapting practice (McPhee et al., 2018). A by-product of transdisciplinary innovation is that the integrated solution returns to the disciplines or to the social order from which it developed and creates potential for effective responses to highly complex problems. Problem solving results in new ethical questions that involve adaptation and learning. In other words, adaptation and learning are inherent to transdisciplinary innovation. However, we argue that there is a much greater potential for transdisciplinarity in citizen science in terms of changes to the social and scientific practices of citizen science as collective action. We make the claim that transdisciplinarity is congruent with problem solving, a factor that is explored in more detail in the case studies on the OpenCovid19 community and the *Forschungsfall Nachtigall*. Our approach is aligned with that offered by the Swiss Federal Institute of Technology in Zürich, and the transdisciplinarity network (Lang et al., 2012).

Case Study 1: The OpenCovid19 Community

An informative example of transdisciplinary citizen science work in practice can be found in the OpenCovid19 community that emerged at the beginning of the COVID-19 pandemic, in March 2020, on the Just One Giant Lab platform (Santolini, 2020). While it started out as a do-it-yourself biology project on creating low-cost COVID tests, it quickly grew beyond this narrow, pragmatic, disciplinary approach while keeping its grassroots, volunteer-driven focus. The project was initiated outside of academic research, and the community quickly grew to over 3000 active contributors. They organised themselves into more than 100 sub-projects that covered a wide array of topics, categorised into diagnosis, prevention, treatment, validation, and data analysis/modelling. These individual OpenCovid19 projects included designing and manufacturing personal protective equipment, such as masks and face shields; making prototypes of low-cost ventilators; creating artificial-intelligence-driven apps to predict infections based on self-recorded coughs, and organising webinars to educate school children about COVID-19 and viruses generally.

This diversity of projects demonstrates that the OpenCovid19 community brought together individuals from a variety of backgrounds, including molecular biology, public health, design, web development, data science, and rapid manufacturing, but also skills such as project management, advertisement, and public relations (see a network of skills and how they interconnect in the OpenCovid19 community in Figure 11.1). Importantly, in the individual projects,

community members from a variety of professional backgrounds converged and collaborated to combine the expertise of professional data scientists, anthropologists, engineers, and biologists in these projects.



Note: The figure shows the diverse network of skills of members of the OpenCovid19 community, and how these skills interconnect as a form of transdisciplinary knowledge integration. The skills of the OpenCovid19 community as depicted here include molecular biology, public health, design and graphic design, web development, data science, and rapid manufacturing, as well as project management, advertisement, and public relations.
Source: Santolini (2020).

Figure 11.1 Map of shared skills across COVID-19 projects on the Just One Giant Lab platform

An emblematic example of the transdisciplinary approach taken by many of the OpenCovid19 projects is the Quantified Flu. This project was begun by members of the Quantified Self and Open Humans communities from outside of academia. It developed into a larger co-creation process that involved a heterogeneous community developing a collective self-tracking system to monitor symptoms of infection alongside wearable sensor data (Greshake et al., 2021). In this example, the team of volunteer contributors was highly diverse in terms of professions, competences and skills, and career stage. Biology undergraduate students were engaged in prototyping different data visualisations, which were translated into interactive

web dashboards by a graduate student in engineering. At the same time, a software developer volunteered his expertise to implement numerous data import options for different wearable devices; a mobile app developer contributed by creating a dedicated app for smartphones; and a trained journalist dedicated time to do outreach and recruitment. A sociologist investigated the co-creation process, and the project recently culminated in an academic publication that highlights both he transdisciplinary collaboration that was based on volunteer contributions from a variety of disciplines and included contributors from across the globe (Greshake et al., 2021). In addition, the project outcome was the prototype implementation. In particular, this innovative project highlights that the outcome of volunteer engagement led to an improved fit between digital tool and real user needs, resulting in an exceptionally high use over a period. Diversity among team members is found in many of the OpenCovid19 projects that were aimed at rapidly creating and testing innovations to combat the emerging pandemic. The potential of transdisciplinary citizen science approaches is confirmed by these projects.

Case Study 2: *Forschungsfall Nachtigall* – a Citizen Science Project on Nightingales in Berlin

The citizen science project called *Forschungsfall Nachtigall,* initiated within academia and managed by the Museum für Naturkunde in Berlin, Germany, studied the natural and cul- tural history of the nightingale in Berlin, by associating various disciplines in science and arts (interdisciplinarity) with different research questions. More than 3000 citizen scientists recorded and analysed over 7000 geotagged recordings of nightingale songs, using an app called Naturblick. Migrants with refugee status, who had recently arrived in Berlin, were a target group of this project because it offered several cultural ways for community engagement. One approach actively encouraged participants to contribute stories about nightingales – these stories could be of their previous interactions with or sightings of nightingales in other environments. While most of the stories related to observations of nightingales in Germany, some were also contributed by refugees and related to observations of nightingales in other regions of the world. Participants in the project were invited to contribute their local knowledge and cultural associations with nightingales. The visible and tangible result is an embroidered nightingale tablecloth with nightingale stories and song locations (Darwin, 2021). This aspect of the project is of particular interest for transdisciplinary citizen science because it demonstrates a form of knowledge integration. The local knowledge of participants who had recently arrived in Berlin was transferred to a new Berlin-based knowledge context through the sharing of stories and accounts of observations of nightingales from elsewhere. Researchers working on the project, as well as other participants in the various story-sharing events and activities during the project, were able to listen to accounts of nightingales and to learn about different contexts – thus, local knowledge was relocated into a new geographical, social, and physical context. Consequently, the project's practice corresponds to our understanding of transdisciplinarity because it applied a transformative ethical practice, moving knowledge beyond scientific standards, while at the same time enriching researchers' and participants' knowledge and cultural understandings across cultural and continental boundaries.

INCREASING TRANSDISCIPLINARITY FOR SOCIETAL IMPACT

The two case studies help to exemplify our understanding of citizen science as a transformative ethical practice. However, for citizen science to have more impact, it needs to become more transdisciplinary. For example, digital tools on the meta side of what defines citizen science demonstrate that the field can move towards transdisciplinarity. In terms of responding effectively to the challenges of the world, the verdict on citizen science is still out, but certainly the European Commission sees the potential of citizen science in responding to some of the major societal challenges of our time. The focus on Open Science and increased science–society collaboration in citizen science resonates with the European Union policies of Open Science, Responsible Research and Innovation (RRI), and "Science With and for Society" ambitions as a way to potentially solve pressing societal challenges. This was important in Horizon 2020, and has continued in Horizon Europe, where citizen science and societal engagement are considered crucial in contributing to excellence, enlarging the scope of research and innovation through the quality and quantity of data collected.

The development, acceptance, and implementation of citizen science relies on public and scientific perception (Riesch & Potter, 2014), and it is strongly impacted by policy development and how it is framed (Hecker et al., 2019). While the citizen science community may have agreed understandings and uses of citizen science, the policy community may have different motivations, expectations, and specifications about it. There is also growing awareness of the need for deeper engagement of the public in science policy (Hecker et al., 2019) by increased attention for the concept of RRI (Stilgoe et al., 2014); RRI requests a more democratic approach to decisions about the directions in which scientific developments should occur (Peter et al., 2018; European Commission, 2013). Participation is included as a key component of research agendas of Open Science and Open Innovation (Nascimento et al., 2018; Groom et al., 2016).

Policy has various expectations towards the outcomes and benefits of citizen science crossing disciplinary and sectoral lines. A qualitative analysis of 43 policy documents from seven individual countries by the European Commission and the Organisation for Economic Co-operation and Development outline expected benefits by citizen science for members of society, science, and policy (Hecker et al., 2019). These benefits include spatio-temporal data collection by volunteers, tapping into distributed knowledge domains, increasing public interest and engagement in research, and enhancing societal relevance of the respective research. Policy documents also attribute educational benefits by fostering scientific literacy, individual learning, and skill development, or facilitating environmental stewardship. In the policy domain, enhanced ownership of research results may improve policy decision-making processes and possibly democratise research as well as public policy processes (Hecker et al., 2019).

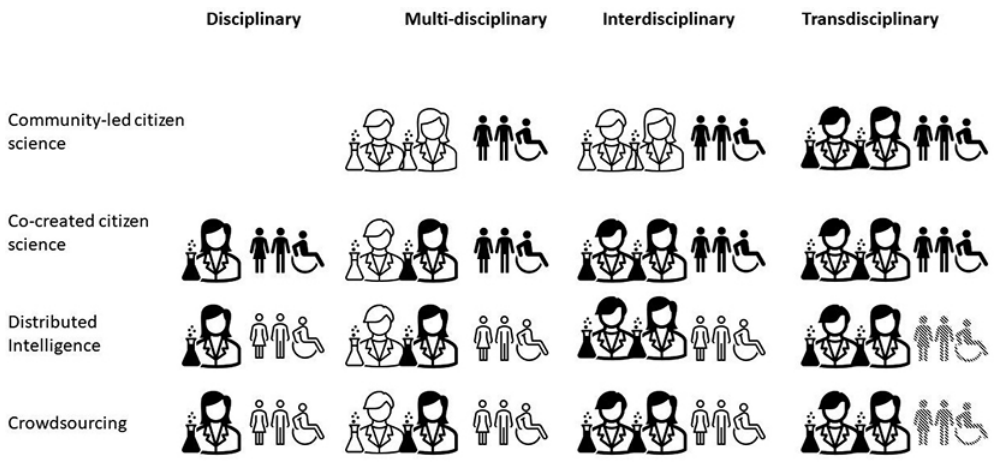
Citizen science also leverages societal capabilities and collective intelligence often excluded from contributions for research and innovation. It facilitates the increased relevance and responsiveness of research and innovation while enhancing behavioural changes in institutions and the public. Citizen science also has the potential to improve relationships between science and society through transparency, co-ownership, and trust of society; also ensuring that outcomes of research and innovation are inclusive, and encouraging mutual learning between science and society, thereby increasing science–society literacy.

MOVING FROM MAPPING DISCIPLINES TO MAPPING CHALLENGES

In the previous sections of this chapter, we demonstrated the complex picture that citizen science presents to an analyst who tries to delineate its contours and structures, particularly given that citizen science is a methodology that is used in multiple disciplines. However, it cannot be considered without due deliberation about how the knowledge that will be produced through it will fit into the specificities of the discipline in which it is deployed. It is plausible to suggest a common framework that will help to explain the transdisciplinary nature of citizen science by considering the way project owners, be they scientists or other professionals, facilitate citizen science independently of what the challenge is or how the knowledge produced is used. At one extreme, a form of citizen science takes place where the "challenge" is set out by a researcher, and then the public is channelled to collect data; the other extreme includes forms of citizen science in which participants are involved in all stages of the process, including formulating questions, data collection, analysis, and reporting.

In Figure 11.2, the actor with the most significant part in decision-making is depicted in black; the other actors, who have a secondary role, and are either following or taking instructions from the project leader, are presented in white, and grey is used to denote potential control. Most of those involved in the project will not have much control over project design or decision-making. Notably, it is critical not to assume that a higher level of participant involvement is beneficial for the project, nor to the satisfaction of participants. For example, in contributory or distributed intelligence citizen science projects, many participants act as sensors and contribute data without any further control over the project. Many participants are satisfied with this situation because they wish to contribute to science with minimal effort. It is therefore important to read the following framework depicted in Figure 11.2 as a range of options, without value judgement about positions. While such value judgement is important within a given context and a specific project, it is unhelpful within the level of abstraction discussed here.

Four types of citizen science activities are presented in Figure 11.2. The Y-axis broadly follows Haklay's (2013) categories of participation in citizen science projects – but it is important to note that the labels for these categories have been modified. In crowdsourcing projects, participants choose to act as sensors, or as contributors of resources (such as by donating unused computing resources of their home computers). Distributed intelligence projects require cognitive engagement and usually involve micro-tasks, such as classifying images on an online platform or recording observations in nature. In co-created citizen science, the project is led by scientists in close consultation with potential participants, and the participants are also involved in refining the research questions, analysing data, and acting on the results. Finally, in community-led citizen science, the roles are reversed, and community members – for example, a group of people that live near a polluting factory – are the initiators and owners of the project. In such projects, the scientists offer support to the community members by providing their expertise to ensure that the project yields useful scientific results. The X-axis denotes the context within which citizen science takes place – disciplinary, multidisciplinary, interdisciplinary, and transdisciplinary. It is important to note that both crowdsourcing and distributed intelligence projects have the potential to engage a very large group of participants – possibly with a group size reaching into the millions - whereas the community-led projects usually have low numbers of participants. The representation in Figure 11.2 uses a fuller



Note: This graphic representation sets out a framework to explain the transdisciplinary potential of different types of citizen science projects, grouped into four non-mutually exclusive categories of crowdsourcing, distributed intelligence, co-created citizen science, and community-led citizen science, and the way project owners, be they scientists or other professionals, facilitate citizen science.
Source: Haklay (2021).

Figure 11.2 A common framework for understanding transdisciplinary citizen science

figure (with filled areas in black) to denote the actor managing and controlling the process, and figures depicted solely with an outline as secondary actors. In the right-hand column, for distributed intelligence and crowdsourcing projects, the figures are hatched to represent partial or potential involvement. It is important to note that the categories of Figure 11.2 are not mutually exclusive; a citizen-led project can use crowdsourcing, and a transdisciplinary project can have a disciplinary core. Furthermore, the categories of citizens and scientists are not mutually exclusive. The figure helps to distinguish who is leading the project and therefore has the greater responsibility for decision-making in relation to the project.

Figure 11.2 represents the potential of transdisciplinary interactions across different types of projects and modes of disciplinary interactions. Working through Figure 11.2, and starting horizontally from the bottom to the top, the potential for transdisciplinarity increases towards the top and the right side of the graphics, predominantly due to the opportunity for novel forms of knowledge production that collaboration supports. Notably, citizen science is valuable activity in all the forms that are presented here, and many participants claim to be satisfied with supporting scientists through data creation or the provision of computing resources. It is therefore important to note that the bottom-left corner of Figure 11.2 should not be viewed as a "missed opportunity".

In crowdsourcing projects, scientists lead the projects and participants make their contributions to the project, with mostly minimal or no interaction between them beyond the recruitment stage of the project. Hence this form of citizen science is very suitable for disciplinary research – the scientist is in control of the design of the protocols for data collection, the algorithms, and tools for sensing, and the participants act as a "bipedal platform" (Nold & Francis, 2017). Some interaction between scientists and participants can occur (for example, through a participant emailing a scientist with a question related to the project), but this is

unlikely to challenge the paradigm of the project and knowledge produced by disciplinary practices. In multidisciplinary projects, a specific member of the scientific team is responsible for the design and implementation of citizen science because they are the one with expertise in engagement, or they need to address an issue from a particular disciplinary perspective. The knowledge produced through citizen science also needs to adhere to disciplinary practices. While scientists who set up the citizen science project may consult with other team members, the citizen science project itself is designed in a disciplinary manner. In interdisciplinary and transdisciplinary projects, interaction and collaboration take place within the scientific team. This is important because the whole team is involved in designing the citizen science project, thereby learning about the methodologies needed to successfully conduct the project. More importantly, the shape of the project and the questions asked address issues that are interdisciplinary by nature. However, learning about how citizen science can contribute to problem solving will probably come from transdisciplinary projects. It is more likely that researchers in transdisciplinary projects will be more open to reach out to participants and involve them in observing the process and potentially influencing the shape of the project. Conversely, because of the limited involvement of participants in the crowdsourcing projects, which are structured around constrained modes of participation, the potential for knowledge production that can lead to transdisciplinary insights is limited.

The second line of Figure 11.2 presents citizen science projects that use "distributed intelligence"; hence, participants contribute through purposeful cognitive engagement, such as through the classification of information online, or through data collection in the field. These projects have much in common with crowdsourcing projects because participants are expected to follow instructions on data collection or analysis, with very limited input beyond the allocated task. However, the fact that the participants are engaged in a cognitive way means that they may have questions and reflect on the task more than in crowdsourcing projects. Therefore, the situation in the disciplinary and the multidisciplinary cases are similar to the "crowdsourcing" examples because scientists set the parameters of the problem. In the interdisciplinary and the transdisciplinary cases, there is an opportunity for participants to comment and to propose new suggestions, and for the research team to listen to these ideas. For example, in the Galaxy Zoo project, participants made suggestions to the project researchers that had not yet been considered, such as identifying images of previously unconsidered galaxies. These pertinent suggestions led to the discovery of new galaxies (Lintott, 2019). It is important to note, however, that these discoveries are within the disciplinary practice of the project and do not beyond it. The example of the *Forschungsfall Nachtigall* case study fits within the transdisciplinary distributed intelligence part of Figure 11.2 discussed here.

In "co-created" projects, there is a deliberate attempt by researchers to engage with participants at early stages of the project and involve them in refining the research questions, designing the data collection methodology, and potentially in the analysis, and perhaps writing results too. In such projects, the potential for transdisciplinarity and knowledge integration is high because participants have different perspectives and different areas of knowledge. Even in the disciplinary example, the collaboration between scientists and participants could add other ideas and suggestions. However, since research is done within disciplinary boundaries, the scientist is likely to limit the degree to which transdisciplinary ideas can be utilised. The act of sharing research with people outside academia is challenging enough, and therefore more conservatism in the methodological design is plausible. Multidisciplinary co-created projects provide limited potential for novel and transformative ideas. In contrast, interdisci-

plinary and transdisciplinary projects facilitate novel ideas and the integration of knowledge. This is particularly true in citizen science because many participants are highly educated and frequently work as professionals; they can contribute to the project in a significant way. The OpenCovid19 case study provides a demonstration of co-creation with the interdisciplinary and the transdisciplinary forms that are highlighted here.

In "community-led" citizen science, the problem definition aspects come from community members. The problems being tackled in community-led citizen science are usually complex and require expertise from multiple fields. However, a lot of integrated, transdisciplinary knowledge will emerge within the community, and not amongst the scientists involved in community-led citizen science, since community members reach out to specific experts to gain their input, and the experts focus on their specific area of competence. There is potential for experts to identify opportunities and to join in projects in a more comprehensive way – in such cases, scientists and community members work in a flat hierarchy where each group of participants appreciates the knowledge of the other. The fact that community members lead and manage the project can create new opportunities for knowledge creation and integration that go beyond the specific project – the Calthorpe Community Garden case study below is one example.

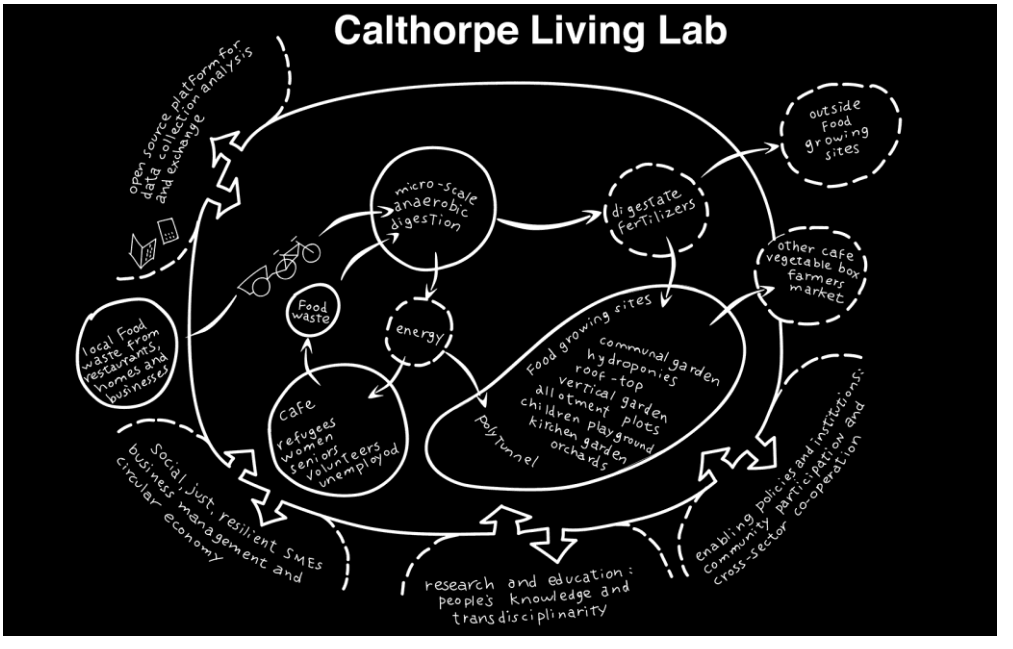
Figure 11.2 illustrates that the landscape of citizen science and disciplinarity is a particularly complex one. The capacity for knowledge integration, and the inclusion of diverse groups of participants, depends on the willingness of different actors to work with new ideas and appreciate different forms of knowledge production. A significant portion of citizen science takes place in the bottom-left of Figure 11.2, either in disciplinary or multidisciplinary research, in crowdsourcing, or in distributed intelligence modes. This limits the potential of citizen science to fulfil its transdisciplinary potential. The following case study on the Calthorpe Community Garden, highlights the complexity of a long-running citizen science project in central London. It shows how community-based citizen science projects can support and build up the infrastructure and governance of future research agendas.

Case Study 3: Community Food Initiatives – Calthorpe Community Garden

Calthorpe Community Garden occupies a site of 0.5 hectares just south of Kings Cross, London. Following a successful local campaign against office development, in June 1983, the London Borough of Camden allocated money to develop the site for gardens, play space, and sports development for the residents of Kings Cross. In 1984, the Garden became a charity and a company limited by guarantee, and recently was designated an Asset of Community Value. Calthorpe's main purpose is to promote, encourage, and make social change by providing a unique combination of indoor and outdoor facilities and services available to all at one inclusive, safe, and attractive location. Aligning with the principles of a community garden, Calthorpe has adopted a bottom-up, participatory, responsive, and collaborative approach to its organisational development, which presents an enabling condition to the idea and practice of citizen science, people's knowledge, and transdisciplinarity, underpinned by the vision that everyone is able to contribute to the production of new knowledge regardless of their back- ground and experience, and create a more just and sustainable world (Figure 11.3).

Calthorpe Community Garden is a community-based model of urban sustainability; an innovative, closed-loop food-waste energy system; and an experimental project integrating research, education, public policy, community development, and enterprise to build a coherent

orce for change (Figure 11.3). It relies on an anaerobic digester receiving waste from their cafe, and other local sources, producing compost, liquid fertiliser, and energy. The fertiliser is then used to produce fresh vegetables for use in the cafe and as a contribution to the foodbank and the cooked meals for vulnerable local people. Compost is available to help local people garden and grow their own food. Calthorpe Community Garden aspires to become an open platform for a range of public science education and citizen science projects. A number of citizen science activities have been conducted in collaboration with various organisa- tions (universities, nongovernmental organisations, community groups) to demonstrate how anaerobic digestate can produce quality compost in a reduced time compared to traditional composting techniques; how liquid fertiliser can increase the productivity of food growing and its nutritional properties; and, more importantly, how an asset-based approach to human well-being and environmental health can contribute to reduce social injustice and inequality. Given current and likely future levels of inner-city poverty, ill-health, and poor diet, Calthorpe have endeavoured to make its citizen science projects appropriate to address specific commu- nity needs and interests while being replicable and adaptable to other community groups and organisations.



Note: This figure is a graphic representation of the Calthorpe Community Garden – a situated, site-specific, evolving, and growing field of community-led citizen science over a period of years. Building upon the numerous accumulated integrated knowledge, experiences, and insights depicted in this figure, Calthorpe has a strong foundation and potential to become a hub for community-led citizen science to bring together 'appropriate' enabling conditions and infrastructures that can allow us to reclaim and cultivate the adaptive capacities of citizens and communities to experiment and innovate.
Source: People's Knowledge Editorial Collective (Eds). (2017). Everyday Experts: How people's knowledge can transform the food system. Reclaiming Diversity and Citizenship Series. Coventry: Coventry University.

Figure 11.3 Calthorpe Community Garden

When University College London (UCL) recently proposed to develop land as a world-class Dementia Research Institute, the potential of the Garden and its social and therapeutic horticulture projects to "add value" to this research was obvious. Calthorpe is already committed to a "dementia-friendly environment". New development or regeneration is best done in partnership with the local community and adjoining neighbours. Planning permission was eventually granted, including, within the s106 Agreement, provision for a UCL–Calthorpe Partnership Plan to be developed to work together to help those suffering with dementia and other neurological diseases. A series of citizen science projects have been initiated and delivered, including a community impact assessment of the UCL new Development Scheme on the Calthorpe site, developing measurements of physical and social outputs of the community gardens on people living with dementia, and assessing how food and diet can reduce the risk of having dementia and improve health. This Partnership Plan is an excellent opportunity to explore how community-based citizen science projects could build into the infrastructure and governance for future research agendas and research strategies more broadly. It will ensure that the outputs and outcomes of ongoing research activities will be relevant and accessible for local communities. It will also develop greater evidence and knowledge of how research agendas can be informed by local communities and wider stakeholders.

CONCLUSION

This chapter provides an enlarged understanding of the relations between citizen science and transdisciplinarity. The convergence of citizen science and transdisciplinarity, charting their commonalities and shared histories, provides a common ground to discuss the future potential of citizen science as a transformative ethical practice. We have interpreted transdisciplinarity as the practices of citizen science that move beyond scientific and social standards. However, as previously suggested, citizen science can be transdisciplinary, but it is not automatically so. It needs to challenge the disciplinary domains and the social order between professional and non-professional scientists. Furthermore, in moving away from mapping disciplines to a focus on the challenges and puzzles, citizen science can be seen as a form of problem solving, and a way to focus on project owners, be they scientists or other professionals. The chapter presents a common framework to help explain the transdisciplinary nature of citizen science.

Three case studies – the OpenCovid19 community, the Nightingales project, and the community food initiatives of the Calthorpe Community Garden – have highlighted the crucial importance of catalysing the potential impact of citizen science using transdisciplinary approaches. The OpenCovid19 case study exemplifies the ways in which knowledge integration took place. The Nightingales project's practice corresponds to our understanding of transdisciplinarity as it applied a transformative ethical practice, moving knowledge beyond scientific standards, while at the same time enriching researchers' and participants' knowledge and cultural understanding of nightingales in different geographical contexts. Similarly, with the Calthorpe Community Garden case study, new knowledge and understanding have been generated through the collaboration of diverse participants from all backgrounds. Advancing community-led citizen science at Calthorpe needs to deal with several major challenges – from the division and hierarchy of different forms of knowledge and ways of knowing; to competing underlying ideologies, ontologies, epistemologies, and cosmologies; to diverging governance, management, and communication strategies; to clashing values around power and politics.

While such challenges can become barriers to the successful integration of community-led citizen science for societal changes, they also serve as entry points for possible synergies and opportunities. In this sense, we argue that, as the field continues to develop, citizen science can move one step further towards practising transdisciplinarity.

The case study of Calthorpe Community Garden highlights a key argument of our chapter around focussing on mapping the challenges, rather than disciplinary boundaries, because this is a transformative practice that enables us to be comfortable with uncertainty and not to be fearful of ignorance. Furthermore, all three case studies help to demonstrate the potential for the integration of knowledge and people in transdisciplinary citizen science. Stated differently, the innovative potential of transdisciplinarity and citizen science enables a higher level of integration of different types of knowledge and know-how. Both contribute to the same movement of accessing knowledge, and these vectors involve an ethical dimension that recognises complexity between disciplines and solidarity between people. In this way, our collective point of view on transdisciplinarity and citizen science relies on the transformative practices that consist of not only moving "across" and "between" the scientific standards but also "beyond" them. The methodologies and epistemologies used in citizen science in different disciplines are delimited by those discipline-based protocols in which the activity takes place. However, crucially, there is greater potential for transdisciplinarity in citizen science in terms of changes to the social and scientific practices of citizen science as collective action.

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