CITIZEN SCIENCE AND SOCIAL INNOVATION: MUTUAL RELATIONS, BARRIERS, NEEDS, AND DEVELOPMENT FACTORS

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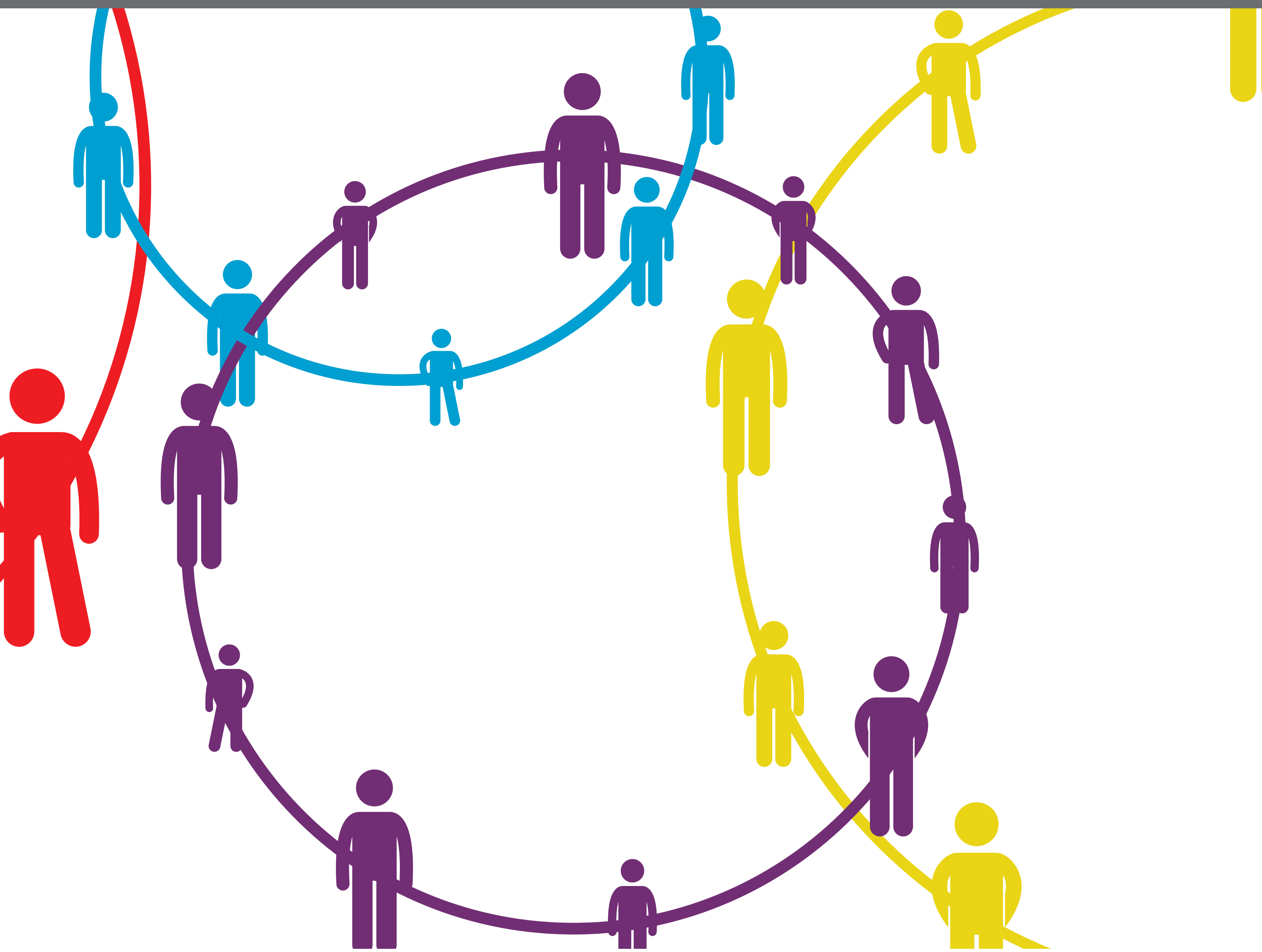

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CITIZEN SCIENCE AND SOCIAL INNOVATION: MUTUAL RELATIONS, BARRIERS, NEEDS, AND DEVELOPMENT FACTORS

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EDITORIAL
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Editorial: Citizen Science and Social Innovation: Mutual Relations, Barriers, Needs, and Development Factors

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Keywords: citizen science, co-creation, co-production, open science, participatory research, social innovation

Editorial on the Research Topic

Citizen Science and Social Innovation: Mutual Relations, Barriers, Needs, and Development Factors

OVERVIEW

The presented Research Topic explores the potential of citizen science to contribute to the development of social innovations. It sets the ground for analysis of mutual relations between two strong and embedded in the literature concepts: citizen science and social innovation. Simultaneously, the collection opens a discussion on how these two ideas are intertwined, what are the significant barriers, and the need to use citizen science for social innovation.

As described by the Organisation for Economic Co-operation and Development and Eurostat (2018), social innovation refers to some new idea, new solution, or new design that makes a social impact in terms of conceptual, process, product, or organizational change, which aims to improve the lives of individuals and communities. This conceptual perspective lays a background for this Research Topic. It is possible to consider citizen science as social innovation. As emphasized by Butkeviciene et al. (2021), the relationship between citizen science and social innovation might be two-fold: citizen science as a novel practice might be considered as social innovation in the realm of the traditional research process, and citizen science might be treated as a vehicle to foster social innovation. These two approaches are present in theoretical debates and coherently intertwined in this collection. On the one hand, articles analyze methodological issues and the novelty of such methods as design thinking or action research. On the other hand, papers also investigate the factors such as translation specifics in citizen science, ecosystems of citizen science, or new learning environments that are supporting the development of social innovation.

The presented Research Topic includes seven articles prepared in total by 34 authors from the following countries: Australia, Austria, Czechia, Estonia, Finland, Germany, Ireland, Italy, Japan, Netherlands, Portugal, Singapore, Switzerland, and United Kingdom. Five journals were related to this Research Topic: "Frontiers in Sociology," "Frontiers in Research Metrics and Analytics," "Frontiers in Communication," "Frontiers in Environmental Science," and "Frontiers in Political Science." This collection contains five types of articles covering: two original research articles (Goi and Tan; Heinisch), one perspective article (Roche et al.), two conceptual analysis articles (Eckhard et al.; Roche et al.), one review article (Scheibner et al.), and one methods article (Coulson et al.).

This Research Topic covers papers that critically evaluate the existing social innovations and citizen science initiatives. The articles are organized according to three themes.

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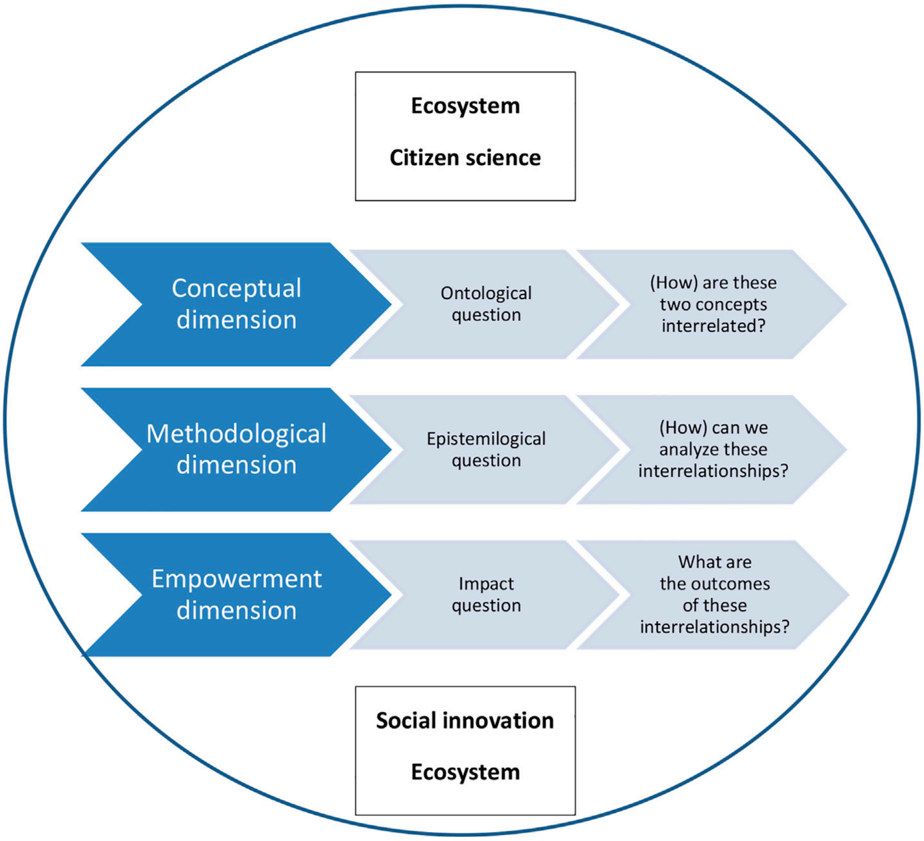

FIGURE 1 | Analytical dimensions of relation between citizen science and social innovation. Source: own elaboration.

THEME I: CONCEPTUAL RELATIONS BETWEEN CITIZEN SCIENCE AND SOCIAL INNOVATION

Until recent years few papers emphasized the relation between citizen science and social innovation. In the presented collection, the team of Eckhardt et al., in their paper, goes further and points that ecosystem of co-creation is an essential feature of citizen science and introduces a form of collaborative scientific work with society. Included results from the H2020 SISCODE project show that co-creation is located inside and between various sectors of society. The subsequent study by Heinisch presents the role of translation in citizen science to foster social innovation. It examines the role of translation and terminology used in citizen science projects and how translation can support (or impede) social innovation through citizen science activities.

THEME II: LEARNING ENVIRONMENTS FOR CITIZEN SCIENCE AND SOCIAL INNOVATION

The second part of this Research Topic contains contributions to studies focused on relations between teaching, learning, citizen science, and their potential relation to social innovation. The study by Roche et al. identifies challenges for successful integration of citizen science into mainstream education systems that also serve as signposts for possible synergies and opportunities. Another paper by Roche et al. continues the topic with a focus on Ireland's rich history in public engagement with science. This study explores several aspects of citizen science in Ireland to assess its development and better understand potential opportunities for the field.

THEME III: METHODOLOGICAL ISSUES IN USAGE AND DEVELOPMENT OF CITIZEN SCIENCE AND SOCIAL INNOVATION

The third theme opens the area to discuss methodological issues. It starts with the article of Goi and Tan, where the authors focus on methodological issues in using citizen science for the development of social innovations, in particular focusing on design thinking is an appropriate approach to be used by the community for future projects. Next, the article of Coulson et al. discusses citizen sensing as social innovation, where authors present data from their 2-year pan-European project. Finally, the paper by Scheibner et al. tackles ethical issues with using Internet of Things devices in citizen science studies.

CONCLUSION

In this Research Topic, the editors wanted to open theoretical as well as empirically-based discussion, including examples, practices, and case studies of at least three types of relations between citizen science and social innovation: 1) domination of the citizen science features over social innovation aspects; 2) domination of the social innovation features over the citizen science aspects; and 3) the ways to achieve balance and integration between the social innovation and citizen science features. Each of these relationships highlights factors that influence the development of the primary scales of sustainability of innovations in the practice (**Figure 1**).

Moreover, the research results presented in the articles of this Research Topic allow the formulation of five directions for further research. These are: 1) dynamics of peer learning and organizational culture in citizen science and social innovation projects; 2) the personal capacity of social entrepreneurs, public managers, citizen scientists, and researchers; 3) design, evaluation, communication, and dissemination of results of the citizen science and social innovation initiatives; 4) digital social innovation and citizen science; and 5) co-creation and co-production processes and their impact on stakeholders (see also Schäfer and Kieslinger 2016; Anderson et al., 2020; Perelló et al., 2021). The editors hope this collection will be an inspiring introduction to studying both identified and yet unnoticed relations between citizen science and social innovation.

AUTHOR CONTRIBUTIONS

The lead author of this editorial is AK. AK outlined and drafted the editorial. EB and MK contributed by reviewing and revising the editorial's manuscript. AK, EB, and MK led editorial work on all manuscripts included in this Research Topic. All authors of the papers listed have made a substantial, direct, and intellectual contribution to the work as well as approved their papers for publication.

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CONCEPTUAL ANALYSIS
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Ecosystems of Co-Creation

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Citizen science is becoming increasingly important as a new and participative mode of knowledge production. An essential element of citizen science is co-creation. Co-creation is by no means limited to a modus operandi for participatory science, but introduces a form of collaborative way of working with society in the sense of citizen science. Results from the H2020 SISCODE project show that co-creation is located inside and between different sectors of society. This article focuses on the question of how co-creation can be better understood in different contexts, and presents a heuristic model that has already been used for case study analyses in the SISCODE project. After an introduction to the field of co-creation and a brief description of the heuristic model, its capability is exemplarily demonstrated *via* application to two selected cases, followed by a discussion of central learnings and implications for further research on co-creation.

Keywords: co-creation, social innovation, design, citizen science, ecosystem

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INTRODUCTION

In the last decades, there has been an increasing political will in the European Union to democratize innovation processes and to strengthen societal participation in innovation and research. A major reason for this development seems to be the goal to find better solutions for social problems with the participation of all actors affected by these solutions (BEPA, 2010). For this purpose, the concept of responsible research and innovation (RRI) and the idea of mission-oriented research were established (Mazzucato, 2018) and became prominent. The call for more participation of civil society in research and innovation is linked to the rise of citizen science, a concept that refers to the opening of science toward society (Hecker and Wicke, 2019; Ostermann-Miyashita et al., 2019). Tried out by natural sciences with a focus on sustainability, this concept is nowadays shaping practice-oriented research in social science, too (Kullenberg and Kasperowski, 2016; Hecker et al., 2018). Not only science opens up to society but also politics and business involve citizens in producing new knowledge and in developing innovations. The results are increasingly participatory, joint innovation processes produced by various stakeholders with diverse knowledge and stakes and from various contexts. Such joint, participatory innovation processes are described with the concept of co-creation (Leclercq et al., 2016; Hochgerner, 2018). In this respect, co-creation, understood as a participatory multi-stakeholder innovation process, forms the context in which citizen science is realized. However, despite a consensus on the participative, cross-sectoral character of co-creation, comprehensive definitions are still not established in research. Co-creation can be understood as a method, process, or service (Sanders and Stappers, 2008; Brandsen and Honingh, 2018). It can be used in the public sector, society, business, and universities (Voorberg et al., 2014; Jørgensen, 2018). One of the main characteristics of co-creation is the value of collaboration with different stakeholders, the creation of a collaborative platform, and the involvement of stakeholders in different innovation processes (Leclercq et al., 2016; Hochgerner, 2018). Some authors recognize at least three types of co-creation with citizens: co-implementation, codesign and initiation, and processes in which citizens participate in different ways (Voorberg et al., 2014).

In SISCODE (codesign for society in innovation and science), a three-year European Union–funded project, the use of co-creation led by design principles takes center stage. Assuming that the use of design methods and principles plays a crucial role in co-creation and its successful implementation, SISCODE wants to make sense of practices of co-creation by design ("co-design") in different contexts. From the successful implementations of co-design, conclusions should be drawn for a better exploitation of co-design in the fields of RRI and policy-making. To do so, a theoretical background through an analysis of European cases and real-life experimentations was developed. The research heuristic, used as a lens to examine practices of co-creation and factors influencing their success and failure, is presented in this article. In line, this article argues that success and failure of participatory innovation processes must be understood through different and interlinked factors on distinguishable levels within any given ecosystem. Its specific contribution is the exemplary application and discussion of a social innovation ecosystem heuristic, developed by Kaletka et al., (2017, 85), to the field of co-creation. Furthermore, the discussion also highlights potential for a further development and application of the model, based on the experiences made during its actual application in the process of analysis in the SISCODE project. Therefore, the aim is to answer two questions: (1) What can be learned from the application of the research heuristic from social innovation research to the analysis of co-creation ecosystems in SISCODE? (2) What conclusions can be drawn from this application for future research? This article, hence, contributes to a better understanding of the research object of co-creation. Although co-creation concerns traditional research fields, it is at the same time a separate field of research, not despite its interdisciplinary and transdisciplinary character, but precisely because of this character. While co-creation is a modus operandi of specific participatory activities across fields like policy-making, service, and product development, it is not limited to single domains and cannot be understood with a focus limited to, for example, politics, engineering, or economics. A major starting point for this article is the thesis that co-creation can only be understood from a transdisciplinary perspective, hence, taking into account its context-specificity with a variety of problems addressed by a variety of actors.

ECOSYSTEMS OF CO-CREATION AS AN EMPIRICAL FIELD

This section creates an overview of the terms and concepts used in this article with the aim to provide guidance and a joint understanding. As this article seeks to share experiences from studying practices of co-creation in different fields of action and various settings, *Co-Creation and Its Different Contexts in Innovation* elaborates different approaches to co-creation to illustrate its conceptual proximity to the field of social innovation despite their differences. Building on that, *An Open Heuristic to Social Innovation Ecosystems* details this proximity to introduce an open heuristic model, which can serve as a search pattern to describe both social innovation and—with adaptions presented in this paper—co-creative initiatives and practices. Leading over to the case-study examples of its application, *Application to Co-creation Initiatives* briefly explains how the heuristic was adapted for the SISCODE project.

Co-Creation and Its Different Contexts in Innovation

Co-creation has been a widespread concept implemented in marketing, whereas other fields have recognized its valuable elements of collaboration, value-creation, and as an engagement platform (Leclercq et al., 2016). Research shows that the understanding of co-creation is changing and nowadays it is not only seen as a method but also as a process where different stakeholders are involved in different stages of an innovation (Leclercq et al., 2016; Hochgerner, 2018), or as a part of a system where organizations are involved to make decisions. Some of these perspectives are presented in the following.

Co-creation as a method is used in design as a way to promote participatory practice (Sanders and Stappers, 2008). Design co-creation is also a method in action research, in which workshops with stakeholders are facilitated in formal design (Jones, 2018, 8). Besides these methods, co-creation is also used as design focus on collaborative processes involving different stakeholders to generate ideation to guarantee first-stage participation of all actors affected by a future solution.

Co-creation as a process or service is a perspective that comes from business, which became popular in the public sector (Brandsen and Honingh, 2018, 9). In contrast to Brandsen and Honingh (2018), Voorberg et al., (2014) distinguished between three types of co-creation: citizens as co-implementer (citizens are involved in services implemented by government), citizens as codesigner (citizens are involved in the process of service), and citizens as initiator (citizens take up the initiative). Besides the public sector, co-creation is also concerned at a strategic level—when citizens are involved in initiating the general planning of a service (Brandsen and Honingh, 2018, 13). In this interpretation of co-creation, service is in foreground, whereby its initiation and planning are in the focus.

Regardless of whether co-creation is conceptualized as a method, process, or service, it can be summarized as an intervention that changes the way things are done in several fields. In particular, it addresses changes in traditional cultural and organizational practices from a top-down approach to a bottom-up approach in which citizens or end-users become actors in a development process. The field in which co-creation takes place is a crucial dimension to observe when trying to describe and analyze the modes of action of co-creation and the changes it triggers.

The following explanations seek to shed light on an understanding of co-creation in its contexts, leading to the general notion of co-creation as a partial practice of social innovation processes and participative innovation processes in more general terms. As elaborated, co-creation is a way to collaborate for decision-makers, experts, and other stakeholders in various contexts (Jones, 2018, 14). In large organizations, for example, in the public sector or healthcare system, the collaboration through co-creation activities is used to optimize products or services (ibid). Co-creation promotes a culture of innovation (Sørensen and Torfing, 2015) because it engages stakeholders who are not usually involved. Through this process, different stakeholders do not only collaborate but also experiment. It also allows the development of their skills and opens up a new field for innovation practices, which can be applied in different societal sectors and social services. In the public sector, it refers, for example, to the commitment of citizens in policy-making through the early-stage participation of citizens in the definition and solution of local problems. In business, it refers to providing the "user" with an active and collaborative role at various stages of the process (Maase and Dorst, 2006; Voorberg et al., 2014), what is often used by entrepreneurs and start-ups. Finally, co-creation in academia and science is observed through spaces of exchange between citizens and researchers, whereby citizens participate in the research process (e.g., citizen science) (Voorberg et al., 2014).

An overall perspective of co-creation shows that it pursues a nonlinear logic, which embodies a multi-dynamic and multi-contextual process. It is often described as a bottom-up approach (Kumari et al., 2019) that operates on different levels whereby citizens and other stakeholders are the key actors. Stakeholders with different backgrounds in culture, belief, and knowledge take different roles and integrate them into a co-creation process. To take this into account, the tools, instruments, and methods used within the co-creation process need to be well aligned and suitable for the respective contexts to promote its success.

As recent research indicates, processes of co-creation are frequently driven by design principles, often without any notice or intention from initiators or participants (Rizzo et al., 2018; Smallman and Patel, 2018). The introductorily mentioned project SISCODE is dedicated toward these specific practices of co-creation and delivers insights and evidence to stimulate openness toward co-creation in science, technology, and innovation (STI), policy-making, as well as in responsible research and innovation (RRI). In the project, co-creation is understood as "a bottom-up and design-driven phenomenon that is flourishing across European contexts like FabLabs, Living Labs, Social Innovation, smart cities, communities, and region" (Eckhardt et al., 2020a, 10). The overall aim of the project is the description of various co-creation approaches in different fields and their respective ecosystems to understand social dynamics (Eckhardt et al., 2020a, 11). Once implemented, the cultural and organizational transformation through co-creation can be seen in established practices and power-shifting policies.

These explanations already point to the close relation of co-creation to social innovation, understood as a new configuration of practices with the overall goal to address social problems in a way they were not addressed through established practices before (cf. Howaldt and Schwarz, 2010). As co-creation involves new social practices and new modes of interaction, it can be considered as an emerging and currently diffusing social innovation itself. Furthermore, Terstriep et al., (2020) emphasized that processes of social innovation are often determined by co-creation, because cross-sectoral cooperation and the participation of all actors involved are a success factor for its emergence and fruitful development (cf. Carayannis and Campbell, 2009). Therefore, co-creation can be conceptualized as an important partial practice within the process of (participatory) social innovation processes. In either way, the question rises why some practices gain momentum, become implemented, normalized, and routinized, and some other practices decline and vanish. At this point the latest the totality of contextual factors, influencing the pathway of practices of social innovation and co-creation, for example, cultural and organizational structures, becomes relevant. The next section is dedicated to a deeper description of this ecosystem and lays down a way to openly examine it in empirical research in the field.

An Open Heuristic to Social Innovation Ecosystems

The concept of ecosystems originally comes from the natural sciences, where it defines a community of organisms and their environment in an interactive and complex system (Willis, 1997). This concept has been transferred across disciplines, including the social sciences, where community capacity has been added as a key element (Donoghue and Sturtevant, 2007).

A review of the literature shows that the concept of the ecosystem provides a framework for understanding and studying the interaction of various actors, institutions, and contexts in society (Kumari et al., 2019). One of the main research questions in the literature is as follows: What are the key dimensions and what are the barriers and drivers of an ecosystem (Bason, 2010, 25)? However, there is a lack of common understanding of the concept, so there are major difficulties in comparing ecosystems (O'Neill et al., 1986; Edquist, 2011). Although there is a gap in the literature with a unified perspective (Terstriep et al., 2020), more recently, some efforts have been made to understand the social, cultural, and institutional aspects of an ecosystem. For example, earlier research shows a focus on the business ecosystem (Anggraeni et al., 2007; Williamson and De Meyer, 2012; Spigel, 2017), while other studies explore innovation ecosystems (Adner, 2006; Adner, 2012) and more recently social innovation ecosystems (Kaletka et al., 2017; Pel et al., 2020; Terstriep et al., 2020). Authors such as De Vasconcelos Gomes et al., (2018) recognize that there is a transition in the theoretical perspectives of business ecosystems to innovation ecosystem. They point out that one of the main differences between business ecosystems and the innovation ecosystem lies in the value of co-creation practices "innovation ecosystem is related to value creation while business ecosystem refers to value capture" (De Vasconcelos Gomes et al., 2018, 31).

Social innovation ecosystems are complex systems of interaction between various stakeholders. Co-creation practices in social innovation ecosystems refer to the agreement between multiple stakeholders (Kumari et al., 2019; Jütting, 2020; Pel et al., 2020) to achieve a common goal. This means that within an ecosystem, there is more capacity generation than as an individual; this is because actors enhance their own capacities by acting together (Jütting, 2020). These agreements between multiple stakeholders are seen as networks, which help to create and share new social practices (Pel et al., 2020).

Other perspectives on the ecosystem focus on geographical space, which means that national, regional, and local innovation systems exist (Edquist, 2011). However, this perspective may raise concerns about the strong diversity of rules, norms, and practices, as recognizes that comparison are difficult (Edquist, 2011, 37). Scholars such as Terstriep et al., (2020) applied a regional perspective to social innovation ecosystems, including actors, institutions, knowledge, and innovation pathways as main elements of analysis. This perspective has the advantage of showing multilayers that define each process of the innovation.

In order "to understand the ecosystem as the comprehensive organizational, institutional, and cultural setting in which the SI [social innovation] is embedded" (Kaletka et al., 2017, 85), the SISCODE cases were examined alongside a multilayered heuristic model in an explorative research process. Building upon a theoretical approach from media science, known as the "Onion-Model" (Weischenberg, 1990, 53), which strives to explain different spheres affecting journalistic acting and content generation, the heuristic provides a kind of searchlight to the right questions to ask, depending upon the research interest. The model is providing a starting point taken up and extensively adapted for social innovation research. It elaborates four units to observe: a context of norms, a context of structures, a context of functions, and a context of roles. These layers and their interrelation can be used as a lens to describe certain dynamics within a social innovation initiative or to identify and further examine drivers and barriers affecting its development:

- The **context of norms** encloses a perspective on "societal framework conditions and challenges" like "professional and ethical standards, historical and legal conditions, codes, and other accepted social standards" (Kaletka et al., 2017, 85). Hence, this context can be seen as an approach to analyze factors on the societal macro-level.
- The **context of structures** can be understood to enclose the meso-level, taking up a rather structuralist perspective. It explicitly encloses "constraints and path dependencies because of existing institutions, economic, political, and technological imperatives." For instance, "the setup of a city administration, restricting what can be achieved on the role and functional context, or the political orientation of the government." (ibid.)
- Both the context of functions and the context of actors are aimed at the societal micro-perspective. For the **context of roles**, the authors suggested to look at "socio-demographic factors and roles of social innovation stakeholders and beneficiaries [...]. This includes these actors' political and social attitudes, motivations, socialization, self-concepts, image, capabilities, and skills." (ibid.)
- The **context of functions** encloses "management procedures, business, and governance models," "how different actors are interlinked and collaborate, how they adjust their roles in a wider network context, and how the network is governed." (ibid.)

Of course, they cannot be distinguished incisively as their overlapping is possible. Furthermore, they are highly interrelated and dependent upon another. The context factors of relevance must be determined and put into relation during the research process. Hence, the model can be understood as one possible initial structured approach to an ecosystem in which a specific social innovation process takes place to explore specific dynamics of interest and their driving and hindering factors.

In example, Komatsu Cipriani et al., (2020) applied the model for the analysis of social innovation cases "in order to understand the ability of design to foster the development of robust ecosystems" (Komatsu Cipriani et al., 2020:1012), whereas Eckhardt et al., (2017) applied it to digital social innovation and its potential for inclusive societies. In the SISCODE project, the heuristic model was adapted to examine co-creation processes alongside the findings and theoretical groundwork provided in the first project stages (Rizzo et al., 2018; Smallman and Patel, 2018). In the following section, the adaption of the heuristic model is presented.

Application to Co-creation Initiatives

Social innovations can be the goal and result of co-creation, for instance, political innovations, technical innovations, or service innovations. In both social innovation and co-creation research, the examination of ecosystems plays a decisive role in order to achieve a comprehensive understanding of its embeddedness. Against this background, the heuristic was adapted for the analysis of co-creation by design in the European research project SISCODE and provided a basic, open, analytical grid for the data collection in the different phases of research. For this analysis, 135 cases of co-creation from all over Europe have been collected and quantitatively evaluated (Eckhardt et al., 2019). In addition, a qualitative in-depth examination of 55 cases was carried out (Eckhardt et al., 2020a; Eckhardt et al., 2020b). As a project with a European focus and cases from all over Europe, SISCODE needed an instrument that made a context-sensitive analysis possible and that could do justice to the different environments of the single and diverse co-creation cases. In this way, the heuristic serves as a central analytical tool and grid for the research activities in SISCODE. In line, the qualitative analysis of the 55 cases was based on the content of the heuristic model, and the data were coded by means of a qualitative content analysis, based on categories that go back to the heuristic model and its four contexts (i.e., norms, structures, actors and roles, and functions).

In the first phase of research, an extensive review of existing practices and literature of co-creation in RRI and RRI policies has been set up (cf. Smallman and Patel, 2018; Deserti et al., 2019). The main results fed into the heuristic as "sensitizing concepts" to enrich the presuppositions on contextual factors of influence for the processes of co-creation. The role of design as focus became a cross-cutting theme to be observed. In example, the single layers were underpinned by the following presuppositions:

- On a normative context, political and normative frameworks had to be observed, as well as the attitudes toward co-creation by design as an accepted practice were of

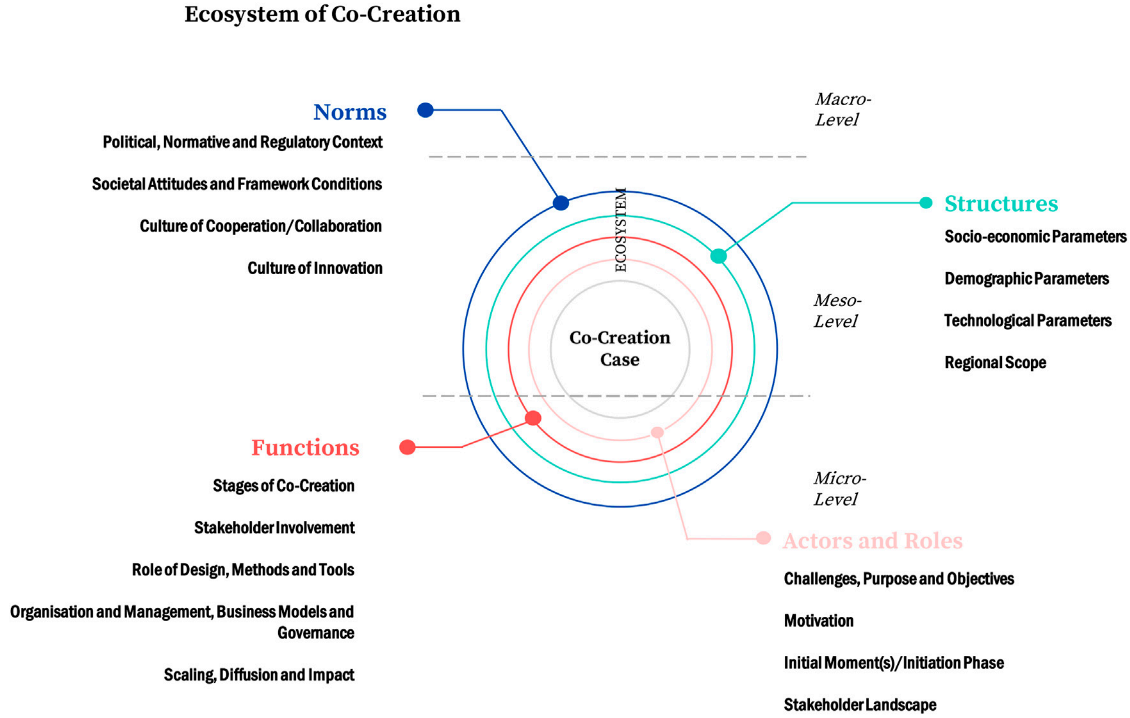

FIGURE 1 | Ecosystem of Co-Creation (Source: own; based on Kaletka et al., 2017).

interest. It was an attempt to elaborate the overall culture toward collaboration in different ecosystems.

- Structurally, especially descriptive factors were thought to be of interest for the embeddedness of co-creation (e.g., socioeconomic or demographic parameters) or the technological and financial equipment of an initiative, as it became clear from initial research that resources always determine the success of co-creation.
- On a functional context, it was taken into account that "Methods and objectives of co-creation need to be explicit and carefully selected to be appropriate to the subject, context, and people," which elucidates the importance to closely examine which tools and methods were used, how, and their evaluation by different people with different roles in the process. In addition, it became evident how structural factors (regional level and institutional level) might determine the tools and instruments.
- Last, initial research emphasized the predominant significance of the "role-context," leading to an emphasis of this layer of participating actors and their roles (e.g., as experts or lay people, interested citizens, or scientists) in the second, empirical research phase.

The adaptions resulted in the following **Figure 1**, as a schematic representation of the heuristic model:

To further illustrate the empirical research, the next chapter presents two examples from RRI (Ilona robot) and policy-making (Sharing City).

EXEMPLARY APPLICATION OF THE HEURISTIC MODEL

The following cases illustrate two processes of co-creation in different contexts. The two examples were selected from the collection of 55 case studies and innovation biographies from the SISCODE project (Eckhardt et al., 2020b) because they represent exemplary cases that make the different levels of the heuristic model of co-creation more visible. Thereby, these two cases were chosen because of their interesting and at some points controversial co-creation processes—Sharing City Umeå that faces more on social (new social practices through citizens engagement) than on technological innovation (of robots in elderly care) as Ilona robot. Moreover, both cases show how the heuristic model of co-creation works and which learnings arise. These cases have been further described and analyzed as innovation biographies (Iasillo, 2020; Wascher, 2020). For both cases, interviews with experts on the cases were conducted to complement information initially gained from desk research. For the first case, Ilona robot, two expert interviews were conducted, and the co-creation process was documented through the Lahti Living Lab, where researchers identify the impacts and acceptance of care robot implementation through the approach of Human Impact Assessment (Iasillo, 2020). For the second case, Sharing City Umeå, three interviews providing additional information were conducted (Wascher, 2020). The case studies and innovation biographies provide the basis for the exemplary application of the heuristic model in this chapter.

TABLE 1 | Overview of the Layers of the Co-creation Ecosystem (Source: own; based on Iasillo, 2020; Wascher, 2020).

Layers of Co-Creation	Illona Robot	Sharing City Umeå
Actors	• Municipality • Researchers • Elderly care staff • Elderly • Students of health care	• Municipality • Municipal companies • Construction companies • Local government (Umeå) • Citizens • Funders
Functions	• Co-creation activities to test acceptance of a robot among elderly and elderly care staff • Participation of citizens and elderly in public health • Interaction among municipality, researchers, clients (elderly), and elderly care staff	• Co-creation to encourage participation • User-centred design study for sustainable planning • Users' involvement • Problem identification refers to the goal to make sustainable mobility easy and effective • Prototyping to develop and test new solutions • Idea around project is scaled with results of subprojects
Norms	• More acceptance of clients (elderly) after interactions with the new technology • Cooperation and partnership	• Sustainable urban development as a political strategy (comprehensive plan for Umeå municipality) • Partnerships • Part of a long-term national innovation initiative
Structures	• Demographic challenge of aging population in Finland • Elderly care services	• Promotion of climate-friendly choices in everyday life

The first case, Ilona Robot in Finland (Iasillo, 2020), represents a case that introduces new technology for elderly care. This case especially shows how different stakeholders, such as municipality, researchers, and elderly care staff, worked together, and how a culture of cooperation and partnership was used in a small municipality to modernize elderly care and change perception of care services in Finland with the first robot in elderly care. The second case, Sharing City Umeå in Sweden (Wascher, 2020), shows the processes of co-creation for policy-making in sustainable cities, not only at the macro-level but also at the local level. This case especially shows the involvement of local government in the development of new solutions and partnerships with citizens and funders to manage the city's population growth through social, ecological, cultural, and economic sustainability. The following **Table 1** provides an overview of the main elements of both case studies and their different layers of the heuristic model for the purpose of comparison, whereas *Ilona Robot and Sharing City Umeå* provide an exemplary analysis of striking aspects of each layer.

Ilona Robot

The case "Ilona Robot" is a design-driven phenomenon that was developed in Finland. A service robot was introduced in elderly care services in Lahti (a city in Southern Finland) in 2015–2016 to face the demographic challenge of aging population in Finnish society. Thereby, the provision of sustainable care in times of a shrinking workforce was facilitated by the interaction among ecological, economic, and social actors as well as the introduction of (new) technologies to shape the sustainable elderly care in Lahti. To do so, co-creation activities are used to introduce the humanoid care robot "Ilona" as a new technology in elderly care, considering the role of elderly patients and care professionals. This initiative comes from the Lahti municipality that started activities among city officials, researchers, and care workers in December 2015 to April 2016 to improve technology-assisted care for elderly people through robots. During the design phase, the Lahti municipal, the Lahti Living Lab, and care professionals planned co-creative activities, whereby the needs of policy-makers, researchers, and care professionals, as well as the needs of clients were considered. In the implementation phase, Ilona robot was brought into two care homes and one geriatric rehabilitation hospital chosen by the municipality. In this stage, different stakeholders participated: on the one hand, elderly as users; on the other hand, students of health care who were trained to become acquainted with new technologies in elderly care. The interaction and impact of elderly care was monitored by the Lahti Living Lab, and a change of mind was observed after seeing that clients interact with Ilona robot. Ilona robot is still in use in the three abovementioned facilities, and it is started to use in a fourth one. Overall, Ilona robot is a top-down initiative that focuses co-creation in RRI and policy-making among different stakeholders.

The Context of Norms

The case of the Ilona robot (Iasillo, 2020) shows the political context and the political will in the region of Lahti, where it was in the interest of the municipality to spread acceptance and familiarity with the robot for the care of the elderly. This is not only because of its will but also because the financial resources for health care are not only a matter of the central government but of different levels of government, insurance, employers, and other actors. Due to the decentralization of health care, it is possible for the regions to make more autonomous decisions and implement innovative policies in the municipalities. Besides the will of the municipalities, there is also an attitude of the Finnish society that perceives the robots as a positive element in the society (European Commission, 2015). This social attitude facilitates the introduction of innovations in health care. This case has an exemplary culture of cooperation and partnership between the municipality, the university, the public sector, and the private sector, giving place to the first robot in elderly care in the municipality.

The Context of Structures

As a region with a significant decline in the industry in the 1990s, Lahti has shifted from the industrial sector to the service sector. Finland, like many European countries, has a large population over 65 years old, and in the last thirty years, this population has almost doubled (13% in 1990 to 22% in 2019) (Statistics Finland's PxWeb databases, 2020). In Lahti, for example, the population over 65 years old in 2019 was above the national average of 24% (Statistics Finland's PxWeb databases, 2020). Therefore, the demography in Finland shows the need for a change in the health sector and a modernization of the elderly care. The municipality of Lahti is a region with very few universities and as such has a very low budget for research and development (R&D). Compared to Helsinki, it has a 0.9% share of R&D, while Helsinki has about 42% (Statistics Finland's PxWeb databases, 2017). The case of Ilona robot shows a structural context that promotes innovation in the municipal area due to the high levels of decentralization, but also due to the strong needs of modernization and change in elderly care.

The Context of Actors

The case of the Ilona robot in Lahti is interesting because of the strong involvement of local actors. For example, this initiative started with strong motivation from local residents and the municipality, which at the same time involved researchers from the Lahti University of Technology, LUT, within the framework of the Living Lab in Lahti. This cooperation aimed to integrate the main actors in elderly care, such as elderly care staff and elderly patients themselves. In addition to the participation of local residents, the municipality was very involved in this initiative. This case exemplifies a co-creative work between all the actors involved, especially between the municipality and the Living Lab researchers and between the researchers and the elderly care staff, together with the elderly patients.

The Context of Functions

The participation of stakeholders in the case of the Ilona robot is crucial for the implementation and acceptance of the innovation. This case also shows different stages of collaboration, such as the participation of citizens and users in the public sector. For example, the first stage was the development of an initiate from Lahti's residents and the municipality. Second, the collaboration with the researchers from the Lahti Living Lab was a crucial space for the development and implementation of this initiative. This stage is very relevant as a space that makes policy innovation in healthcare possible, and this stage also involved healthcare students. Third, an implementation stage in which the first healthcare institutions participated in the implementation of this initiative from December 2015 to April 2016. Finally, a private company participated in the implementation by training health workers in two care homes and a geriatric rehabilitation hospital. The co-creation activities took place with the monitoring of the Lahti Living Lab in 2015 and 2016, where researchers measured the Human Impact Assessment to identify the acceptance of care robot among the elderly and elderly care staff. The interaction among elderly care staff, students of health care, and care staff took place in two care homes and one geriatric rehabilitation.

Functions and impact: Some of the most important stages of co-creation in this case were the sharing of responsibilities among stakeholders in the design and implementation phases. For example, during the design phase, the municipality integrated different stakeholders, which revealed the strong motivation of the public sector to collaborate, engage, and integrate the user's perspective into the public sector. In the implementation phase, elderly patients and health workers play an important role, as they have the most interaction with the trainers from the company where the robot was purchased, as well as the interaction for the activities with the robot itself. The evaluation phase was carried out by the researchers of the Living Lab in Lahti by observing and documenting at least twenty-seven activities between Ilona's robot and the elderly patients. The impact of these activities was assessed by observing the impact of the Ilona robot on the care staff (e.g., working environment and competencies) and the impact on the clients (e.g., interaction, and physical and emotional experience).

Sharing City Umeå

The co-creation case Sharing City Umeå (Wascher, 2020) faces the development of the city Umeå (in northern Sweden) by testing new solutions and collaborations concerning sustainability. Thereby, the project is coordinated by the local government that regards and manages the growing population of the city through social, ecological, cultural, and economic sustainability.

Based on the knowledge of a consumption habits survey in 2018 and a travel habit surveys conducted by the city years before, local stakeholders gained concrete insights into the effects different ways of traveling have on climate. In the following, new solutions concerning sustainability—especially in mobility—were tested and supported by initiatives developed by the municipality in Umeå.

In 2019, the idea of mobility service hubs brought together different types of sharing services and products to reduce peoples' travel needs in offering alternative and sustainable mobility solutions. Therefore, from 2020 on Umeå is considered as a testing ground for service and mobility hubs to change citizens' behavior toward sustainable mobility. To do so, six best-practice examples of service and mobility hubs in Europe were analyzed, a case study research was done, and two focus group studies were performed, whereby the first one was about general mobility of the future and the second one about sharing service and mobility solutions for the parking garage Nanna in Umeå (Eckhardt et al., 2020b, 764). In this process, it came into light that user involvement and citizens' engagement are important to come up with feasible, sustainable solutions and to create citizens' long-term mobility needs. "Sharing City Umeå" thus helps to promote socially sustainable development in Umeå. Furthermore, Sharing City Umeå describes co-creation that is derived from and embedded in distinct innovation systems that considers RRI in innovation strategies and funding schemes.

The Context of Norms

The context of norms includes a range of different factors that have a driving or hindering influence on co-creation. The case of Sharing City Umeå exemplifies how different policies can support co-creation through agenda setting on the macro-level. Sharing City Umeå is embedded in and linked to different policy programs, starting from the macro-level (Sharing Cities Sweden and Viable Cities) and down to the local level of local agendas. Furthermore, it is implemented by the municipality of Umeå, hence directly linked to its local policies toward sustainability. At the same time, Sharing City Umeå in turn consists of various subprojects. What all these different levels have in common is that they are closely related to policies aimed at achieving sustainable change. These policies thus initially offer a supporting framework for the subprojects and do not only act as starting points but also act as enablers. Of course, it has to be taken into account that the central role of such policies in the specific context of Umeå and the larger context of Sweden do also lead to path dependencies: co-creation projects that do not address the issue of achieving more sustainability may not benefit from the framework conditions enabled by policies. For the specific case of Sharing City Umeå and its subprojects as a top-down approach, however, such policies are main enablers. In addition, the policy-driven program Sharing Cities Sweden pursues and promotes a participatory approach. In this regard, this policy also represents a very specific enabler because it is fostering the establishment of an environment that is characterized by several co-creation processes in several parallel projects. In this respect, it is supportive not only for projects that may or may not contain co-creation processes but also specifically for co-creation processes themselves. Sharing Cities Sweden also strengthens the exchange between municipalities in Sweden, and this approach—at least indirectly—also strengthens the exchange between the initiators and implementers of co-creation processes across local and regional contexts. At this point, there is also a possible interaction of policy on the macro-level of the context of norms observable with the concrete design of co-creation processes on the micro-level of the context of functions.

The Context of Structures

The case of Sharing City Umeå is an example of how structural factors can play a role in the context of co-creation. At the same time, it shows how such structural factors can be related to norms if structures are to be changed through agenda setting and norm setting by administrative institutions. Specifically, the Municipality of Umea is planning an increase in residents by 2050 and is actively trying to design this process. This structural change in the demographic context is framed by policies that aim to improve the quality of life by strengthening sustainability. This improvement in the quality of life in the sense of sustainable change is pursued in a participatory approach in which citizens are actively involved in various subprojects of Sharing City Umeå. This interplay of the desired structural change in relation to demographics and the setting of policy agendas enables the co-creation processes that are carried out in the case of Sharing City Umeå. At the same time, the existing population structure has an effect on the realization of the co-creation processes within the subprojects on the micro-level and thus the achievement of goals on the macro-level. The population growth of Umeå is to be designed to be sustainable and citizens are to participate in the design of sustainable solutions. The case shows that this public participation actually meets with a positive response. A social environment can be assumed in which value proposition tends to be present that enables sustainable solutions with the participation of citizens. This exemplifies not only a connection between demographic structure and administrative agenda setting but also a connection between demographic structure in the sense of the composition of milieus and the success of the co-creation process insofar as stakeholders are willing to participate.

The Context of Actors

Diverse actors are involved in the co-creation process. On the one hand, companies focus on sustainable aspects in water, energy, or other environmental points. On the other hand, the parking space provides with the parking garage in Nanna, where the emphasis was on. This case thus integrates actors who mainly deal with the societal challenge of environment protection and sustainability. Moreover, concerning the roles of the abovementioned actors, Sharing City Umeå is quite interesting because of the actors' overlapping roles. For example, the funder/investor motivated and supported the initiation of the initiative, which is why the role of funder/investor and the role of initiator overlapped. Another meaningful point is user involvement and citizen engagement. By involving different groups of inhabitants of Umeå, different user perspectives are considered. Moreover, all citizens had an intrinsic motivation and interest in participating. This exemplifies a co-creation process that grounds on highly motivated citizens and their willingness to participate but not to initiate co-creation processes.

The Context of Functions

The role of methods in the case of Sharing City Umeå is very interesting and illustrates how methods are used to select target groups as well as to collaborate. At first, the method of the stakeholder mapping was used in a workshop to explore possible target groups. After ranking, a consultancy and agency named "Hello Future" was commissioned to design a focus group study. This organization is specialized in digital transformation and facilitates services of design and innovation processes. Moreover, it creates long-term change and innovation. Due to its commission by the municipality, Hello Future designed the abovementioned focus group study with the three selected target groups (young people, families with children, and older couples without children at home), whereby a focused group was running in each target group. All are facilitated by Hello Future and started with an introduction to discuss the upcoming ideas. Thereby, the workshop leader explains and exemplifies the ideas. Hello Future recorded, took notes, and identified existing needs through the discussion. Based on the outcome, Hello Future then collected recommendations linked to user-centered and design-driven approaches. In the focus group, the participants explore their needs and thoughts in a discussion to bring in their perspective as well as to create a good understanding of their needs. Because of this selective way of participants, who were on top recruited from a Facebook campaign, this method had an impact on the projects' results. Moreover, such focus groups are participatory workshops to exchange experiences and to discuss about sustainability in Umeå. A user-centered approach like this also brings users' perspectives into the co-creation process and gets it forward. However, citizens have not participated in the beginning (in the designing). Thus, the focus groups frame co-creation in practice and enable an environment of collaboration. In summary, this shows that methods have an impact on co-creative activities and the way of collaboration.

DISCUSSION

In this article, the concept of social innovation ecosystems was applied to the field of co-creation. We argue that the ecosystemic conditions which support or hinder the successful implementation of co-creation must be carefully identified and examined in order to fully exploit co-creation as a fruitful way to tackle a challenge. To systematize the research design, these supporting and hindering factors can be assigned to different layers of such ecosystems. This article presents the application of a heuristic model of four layers and describes two examples from a comprehensive empirical analysis conducted in the European research project SISCODE. Sharing City Umeå and Ilona Robot are two cases selected from a set of 55 initiatives and co-creation processes which have contributed to the reflections and results presented.

The heuristic provides tools to identify and observe four different, yet interlinked layers: norms, structures, functions, and roles. Thereby it has to be noted that these layers rather provide an overview of the qualitative data from the case studies and biographies. Moreover, one of the main contributions of this article is the adaptation of the social innovation ecosystem model to identify the actors, their roles, and their conditions and interactions in a specific environment. For this understanding, the study of co-creation processes was of great value in identifying more precisely how co-creation is set up within a process of social innovation and how the elements of collaboration and cooperation work. In this sense, already De Vasconcelos Gomes et al., (2018) recognized the value of co-creation within ecosystems of innovation, while other authors (Kumari et al., 2019; Jütting, 2020; Pel et al., 2020) recognized the relevance of agreements and the involvement of a variety of actors in co-creation practices.

The main theoretical implication of the work presented here is that there needs to be a stronger mutual reflection and acknowledgment of theoretical contributions in the fields of social innovation and co-creation. While social innovation research will then be able to dive deeper into the potential and pitfalls of collaborative development processes, co-creation approaches can learn from SI's perspective on (social) impact and societal transformation. In this regard, further research could delve deeper into the relationship between co-creation and social innovation. In this article, a strong proximity of both social phenomena was presented, but at the same time, the differences were highlighted. Accordingly, it seems to be promising to analyze and understand both phenomena in their common context.

One of the main limitations of this study is that it focuses on two case studies to explain a complex model of co-creation. It certainly does not provide a complete overview of all types of co-creation processes nor can it be a generalization within all social innovation processes. But the two cases analyzed in this study provide examples where all layers of an ecosystem are possible to observe and were documented. Nevertheless, we suggest that more research is needed, especially to identify the drivers and barriers of co-creation practices and their forms of institutionalization. The comparisons of two SISCODE cases are an exemplary application of the model. Both are co-creation cases because of their collaborative phases. We see that a normative setting which enables regions to make relatively autonomous decisions and implement innovative policies based on their specific challenges, in this case within the health sector, can help to motivate different actor groups to become involved in finding solutions. In the other case, the common perception of residential structures as dissatisfying helped to define a normative framework to increase the number of residents by 2050 on the one hand triggered the definition of a set of methods and tools for collaboration, and brought together local stakeholders in different roles.

Both cases exemplify how structural factors can play a role in co-creative practices and in the promotion of innovation. Especially the Sharing City Umeå case shows how complex relationships in co-creation ecosystems are. Even if the relationships are complex, relationships support co-creation—as policies in Sharing City Umeå or partnerships between the municipality in Ilona Robot. Moreover, co-creation does ground not only on relationships but also on the integration of multiple actors. This is the reason why co-creative work between all actors involved, for example, municipality, researchers, citizens, and external stakeholders, turned out as fruitful.

Co-creation is a diversified and context-dependent phenomenon. Still, the question remains whether factors can be empirically identified which are universal characteristics of co-creation and independent from particular contexts. The heuristic model could benefit from such anchor points without losing its suitability for various purposes. In contrast to such static anchor points, the model also provides a basis for better understanding dynamics unfolding throughout the co-creation's biography. It helps to answer questions such as the following: How are co-creation practices sustained over time? In particular, what is the impact of the case on the normative layer, on the legal framework? How do societal expectations and attitudes change toward the engagement of citizens and stakeholders throughout the process of innovation or policy-making? And what opportunities and constraints in policy design can be identified which help or obstruct the development of innovation systems based on co-creation?

In sum, the application of the model to the field of co-creation is valuable both from a scientific perspective and for practitioners. Socio-scientific innovation research is interested in better understanding why initiatives succeed, why they fail, and how they contribute to distinct changes or wider transformations in society. Here, the model presented helps to identify drivers and barriers, and thereby elements of success and failure. At least in parts, it also allows to better understand transformation processes related to the initiatives, for example, when initiatives successfully work on changing the societal expectation from or attitude toward participatory policy-making in a city or region. From a very practical point of view, and this is the main practical implication here, the heuristic can serve as a "guiding light" and help to understand what works in co-creation and what not. This would require a translation of the model for practitioners' contexts, an introduction of guiding questions to be answered, and a reproducible way to interpret the results.

In a normative sense, establishing a setting in which co-creation is made easy and becomes a routine can be considered a key factor for thriving social innovation as well as co-creation initiatives. This seems also true for major transformational projects, as "concepts like 'smart' or 'green' city can only unfold their 'true' value for social innovation, when they involve participative modes of governance, social, economic and technical innovation" (Terstriep et al., 2020, 896). So, the model is instructive for the design of an innovation system, especially if this is based on a comprehensive understanding of innovation which includes not only for technological but also for social innovation.

AUTHOR CONTRIBUTIONS

All authors contributed to the article and have read and approved the submitted manuscript. KM and AS conducted the literature review on co-creation. KM carried out the literature review on ecosystems. DK and JE contributed to the application of the social innovation ecosystem model. AS, KM, and DK contributed to the section on empirical cases based on the SISCODE project. CK originally developed the model applied in this work, and contributed to the conceptual development of this article and to the analysis of results.

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The Role of Translation in Citizen Science to Foster Social Innovation

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Citizen science has become a world-wide phenomenon. Especially for citizen science projects that have a global reach, translation is crucial to overcome language and cultural barriers to reach members of the public. Translation, understood as the transfer of meaning (of a text) from one language into another language, is crucial for the transmission of information, knowledge and (social) innovations. Therefore, this paper examines the role of translation and terminology used in citizen science projects and how translation can foster (or impede) social innovation through citizen science activities. Based on a set of predefined criteria derived from the social innovation literature, this paper analyzes the factors that contribute to (social) innovation in citizen science by means of translation. A specific focus of the case study is on the aspects of agency, institutions, and social systems. The results demonstrate that translation in citizen science may support a change of social practices as ingredients of social innovations. Additional research is needed to further understand the implications of translation in citizen science and its effects on social innovation. Nevertheless, this work has been one of the first attempts to examine the relation between translation, citizen science and social innovation.

Keywords: translation, localization, adaptation, social change, terminology

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INTRODUCTION

Citizen science has received considerable attention in recent years. Although citizen science has been practiced for a long time, it evolved as a "movement" only recently. "Citizen science projects actively involve citizens in scientific endeavor that generates new knowledge or understanding. Citizens may act as contributors, collaborators, or as project leader and have a meaningful role in the project" (European Citizen Science Association, 2015). The increased interest in and emergence of citizen science led to a professionalization of the field, the development of a community (of practice) and of principles of citizen science (European Citizen Science Association, 2015; ECSA, 2020). These principles specify inclusion and exclusion criteria to draw boundaries between what can, and cannot be considered citizen science.

The different ways how citizen science is understood have led to new forms of engaging with the public, including aspects of diversity, creativity and social innovation (Schäfer and Kieslinger, 2016). Moreover, aspects such as ethics, transparency, recruitment of participants, including citizen science project platforms, easily understandable data protocols and communication of results to the public as well as co-authorship of citizen scientists in academic publications receive considerable attention in the literature.

Translation and Innovation

However, much less is known about the role of translation in citizen science. Traditionally, translation is defined as the transfer (of meaning) of a text from a source language into a (text in the) target language (Snell-Hornby, 2005). This shows that at the heart of this transfer are not words or languages, but texts. Translation is crucial for all fields of human activity, ranging from governance and economy to culture and literature (Woodsworth, 2013) and it enables communication and understanding between different language communities (Burnett, 2018).

When referring to the translation of citizen science projects or translation for citizen science projects, it must be considered that the texts to be translated are embedded in a context, i.e., a situation characterized by historical, cultural and socio-economic aspects. Translation is thus a form of transcultural communication, a communication determined by a certain purpose and targeted at a certain audience. This purpose (skopos) influences the realization of the translation, including its content, form, style, etc. (Vermeer, 1978).

Translation practice has undergone several changes and translation theory has seen various paradigm shifts. Among the major impacts (or innovations) are technology and crowdsourced translation.

Technological advances, including computer-assisted translation (CAT) tools and machine translation changed the way translators work. CAT tools designate a software that assists translators while translating. They facilitate the translation process by increasing the speed and the quality of the translation. At the heart of a CAT tool is a translation memory, i.e., a database that stores pairs of translation units, usually sentences, in the source and target language that were previously already translated. If the same or similar sentences occur in the text to be translated, the software displays these to the translator (Braun, 2015). CAT tools have therefore drastically impacted the translation process (Christensen and Schjoldager, 2010) since translators now work in a segment-by-segment manner. The positive effects are that it increases productivity and consistency. The negative effects are related to text cohesion and overreliance on translation units suggested by the translation memory (regardless of their quality) (Krüger, 2016). Another technology that impacted the translation process is machine translation. Especially neural machine translation has made major progress in recent years and reaches good quality in various language pairs. Machine translation systems are not only used by professional translators to increase productivity but also by various other user groups, also due to freely available machine translation systems on the Internet. Since both CAT tools and machine translation systems have revolutionized translation processes, they are also helpful tools in the case of crowdsourced translation.

Crowdsourced translation (also partly referred to as community translation or volunteered translation) refers to "translation where the members of the undefined "crowd" act as volunteer translators" (O'Hagan, 2012). Here, "the Internet provides a platform for completing tasks relying on the knowledge of a self-selected community of volunteers on the web" (Jiménez-Crespo, 2013). The Internet and technological advances allow for user participation and online collaboration among large user groups. Crowdsourced translation ranges from the translation of popular culture, including fansubbing, where fans create the subtitles of films or TV programs in another language, to the translation of social media platforms by their users, such as Facebook, or subtitling of TED talks by volunteers (O'Hagan, 2012). Citizen science initiatives also make use of crowdsourced translation, such as the Citizen Science Translation Hub (citscitranslate.wixsite.com/citscitranslate), where crowdsourced translation meets citizen science: "Help us out as a volunteer or proofreader. No experience required, just the ability to speak more than one language!"

Both translation technologies and the crowd help to address emerging translation needs. Both should increase productivity and accelerate the translation of large volumes of text (and reduce costs of translation) (Anastasiou and Gupta, 2011).

However, very little is currently known about the relation between translation and social innovation in citizen science.

Social Innovation

Similar to citizen science, social innovation is a concept that still lacks a uniform definition among the research community. However, in this paper the definition by Howaldt and Schwarz (2010) is used: "A social innovation is new combination and/or new configuration of social practices in certain areas of action or social contexts prompted by certain actors or constellations of actors in an intentional targeted manner with the goal of better satisfying or answering needs and problems than is possible on the basis of established practices".

Social innovation thus results in new solutions, such as products, processes, activities or services that satisfy a social need and enhance a society's capacity to act. Social innovation depends on the contribution and participation of all actors (Portales, 2019). In contrast to other forms of innovation, social innovation is not aimed at maximizing profit and having a competitive advantage but is driven by the concern for communities (a social need or social problem) and results in social change among a large number of people (do Adro and Fernandes, 2020).

Three agents in social innovation have been proposed, namely individuals, organizations and social movements. Although there are also other agents, such as governments and enterprises, these can only coordinate (do Adro and Fernandes, 2020).

Therefore, social innovation depends on agents, on the one hand, and (social) structures, on the other. This means that social innovation is created by agents, i.e., actions or behaviors by individuals (that result in collective actions within a social system) and the external structural context (since a social system is characterized by its underlying institutions). Social innovation, thus, requires action and the reproduction of these actions (Cajaiba-Santana, 2014).

Therefore, social innovation is characterized by innovation, agents, structures or institutions and a social system. Thus, the relationship between actors and structures is key to social innovation (Cajaiba-Santana, 2014). The change that results from social innovation targets social practices. It manifests in "changes in attitudes, behaviors, or perceptions, resulting in new social practices, new institutions, and new social systems that allow visualizing a real transformation of society" (Portales, 2019). Social innovations are rooted in their social context defined by various historical and cultural framework conditions. Therefore, actions and the social context are intertwined (Cajaiba-Santana, 2014).

Social innovators foster social transformation. They can be any actor, i.e., individuals or entire communities independent of the sector of society. However, social change can only be achieved if actors from all sectors participate in social innovation processes, since critical actors are crucial to solve a complex problem (Portales, 2019).

Moreover, another important differentiation in social innovation is the difference between result and process. Regarding the result, social innovation emphasizes the satisfaction of a certain need through innovation, as well as generating new social structures and improved relationships in society. From a long-term perspective, social innovation should increase a society's capacity to act, by being aimed at a systemic societal transformation. Regarding the process, on the other hand, social innovation is a participatory process that enhances the relationship between actors, fostering social resilience and providing access to resources to meet certain needs (also) in the future (Portales, 2019).

Citizen Science as Social Innovation and Citizen Science Resulting in Social Innovation

Citizen science itself results in a change of social practices. Therefore, citizen science can be regarded as social innovation (Butkevičienė et al., 2021). Therefore, we can observe an effect of citizen science (practice) on academia that allows to classify citizen science as social innovation in scholarship. Social innovation and citizen science share many commonalities. Both are cutting-edge, embrace (technological) advances and social objectives. However, it still needs to be investigated if citizen science can produce long-term change in academia and thus also transform social systems.

Although citizen science has received special attention recently, also in (European) funding schemes, the recognition of researchers engaging in citizen science, as well as academic incentives for citizen science activities are lagging behind, such as a proposed social impact indicator (Schäfer and Kieslinger, 2016). This is despite the fact that citizen science can open up academia, which is often characterized as ivory tower, detached from the world "outside", disconnected from reality and practical considerations. However, citizen science is praised as democratization of research (Irwin, 1995) and a means to raise awareness for and knowledge of certain topics, to increase scientific literacy (Bonney et al., 2009; Queiruga-Dios et al., 2020), to change attitudes (Brossard et al., 2005) and tackle societal problems (Dickinson et al., 2013). Moreover, citizen science can result in the empowerment of the participants (Socientize, 2013; Göbel et al., 2019), similar to participatory action research. However, citizen science also faces challenges ranging from data quality considerations (See et al., 2013) to ethical issues such as the exploitation of free labor, or inclusion.

Translation, Citizen Science and Social Innovation

Citizen science has proliferated in recent years, as does social innovation. Citizen science has been framed as social innovation itself, and it can also be the basis for social innovation and, thus, social change. Translation has also been characterized as a means to foster (or impede) change in societies and cultures.

No previous study has investigated the interplay between citizen science, translation and social innovation. Therefore, this study examines the role of translation used in citizen science projects and addresses the question of how translation can foster (or impede) social innovation through citizen science activities.

While some research has been carried out on translation in citizen science projects (Michalak, 2015; Desjardins, 2021) and a Citizen Science Translation Hub was launched (Sheppard, 2020), there is still very little academic understanding of transcultural issues of citizen science and social innovation, especially with regard to the aspect of translation. Based on a case study, this paper explores the ways in which translation is used to meet the needs of the contributing participants and the extent to which translation in citizen science projects can bring social innovation. Understanding the link between translation in citizen science projects and social innovation will help consider these aspects in citizen science in the future.

METHODS AND MATERIALS

This paper examines the role of translation and terminology used in citizen science projects and how translation can foster (or impede) social innovation through citizen science activities.

Based on a set of predefined criteria derived from the social innovation literature with regard to the key dimensions and characteristics of social innovation, this paper analyzes the factors that contribute to (social) innovation in and through citizen science by means of translation. A specific focus is the change of social practices fostered by translation in citizen science activities and the underlying aspects of agency, institutions, and social systems.

A case-study approach was adopted to allow a deeper insight into the translation aspect in citizen science projects that have a global reach. The projects for the study were selected from the citizen science project platform Zooniverse based on their international nature, the availability of the Zooniverse (project) pages in at least two languages, including English, and the consideration of localization.

To examine the role of translation in citizen science projects to foster (or impede) social innovation exemplified by Zooniverse, this study further explores the languages represented in Zooniverse projects, the way how translation is dealt with on Zooniverse and the features of social innovation reflected in translation.

For this purpose, the Zooniverse website was analyzed, in particular the multilingual project pages (active projects under

TABLE 1 | List of social innovation aspects (non-exhaustive).

Aspect	Criteria
Process perspective Cajaiba Santana (2014)	Agency Institutions Social systems
Three dimensions of social innovation Moulaert et al. (2005)	Content (satisfaction of human needs) Process (changes in social relations) Empowerment (increase in socio-political capability and access to resources)
Four key elements of social innovation Portales (2019)	Satisfaction of a need Innovation of the solution Change of social structures and relationships The increase in society's capacity to act
Key dimensions of social innovation Howaldt et al. (2014)	Concepts and understanding Addressed societal needs and challenges Resources, capabilities and constraints Process dynamics Actors, networks and governance
Engaged research Stanton (2008)	Purpose Process Product
Ten social innovation influencing factors Oganisjana et al. (2015)	Openness to novelty Consciousness Responsibility Proactive thinking Lifelong learning Positive experience Passivity Conservative thinking Power distance Bureaucracy
Four layers of social innovation ecosystems Kaletka et al. (2016)	Context of roles Context of functions Context of structures Context of norms
Five main definitions for the concept of social innovation that leads to social change Tardif and Harrison (2005)	Novelty and character of innovation Objective of innovation Innovation process Relationship between actors and structures Restrictions on innovation
Five dimensions of social innovation Tardif and Harrison (2005)	Transformation Innovative character Innovation Actors Processes
Levels of analysis and occurrence of social innovation Cajaiba-Santana (2014)	Intra-social group innovations Inter-social group innovation Extra-group social innovations

zooniverse.org/projects), the general forums (zooniverse.org/talk), the blog (blog.zooniverse.org) as well as the help page (help.zooniverse.org). A list of all active project pages available in more than one language was compiled, including the languages in which these project pages are available. The forums and the blog were searched by using the following keywords: "translat*" (to include translation, translated, translate, translating, etc.), "locali*" (to include localization, localized, localizing, etc.), "adapt*" (to include adaptation, adapting, adapted, etc.) and "language". Forum posts that contained these key words but were not relevant to the current research were excluded from the further analysis. The criteria used for analysis are described in the following.

Criteria of Analysis

The social innovation literature specifies various characteristics, principles and methods of analysis of social innovation (**Table 1**). While, from a process perspective, agency, institutions and social systems can be differentiated (Cajaiba-Santana, 2014), from a dimension perspective, concepts and understanding, objectives (societal challenges, systemic changes), drivers and barriers (including governance), the social innovation cycle and resources, capabilities, and constraints (including finance, regulations, human resources, and empowerment) can be identified (Howaldt et al., 2014).

Additionally, ten factors that have an influence on social innovation are specified: openness to novelty, consciousness, responsibility, proactive thinking, lifelong learning, positive experience, passivity, conservative thinking, power distance and bureaucracy (Oganisjana et al., 2015). Focus group discussions revealed that the six categories *openness to novelty, proactive thinking, consciousness, responsibility, lifelong learning, and positive experience* can promote social innovation if they are present (and hinder social innovation if they are absent). The other four categories (*conservative thinking, passivity, power distance, and bureaucracy*) were identified as factors clearly hindering social innovation (Oganisjana et al., 2015).

Despite the different approaches to the concept of social innovation, it has several key elements. The number of those differs between authors. Social innovation has three key elements according to Moulaert et al. (2005): First, the content or product dimension, which consists of the satisfaction of a (yet unsatisfied) human need. Second, the process dimension, referring to changes in social relations, especially governance and the participation of disadvantaged groups. Third, the empowerment dimension, consisting of the increase in the socio-political capability and the access to resources. An additional key element identified by Portales (2019) is the innovation aspect, thus, resulting in these four key elements of social innovation: the satisfaction of a need, the innovation of the solution, the change of social structures and relationships and the gain of a society's capacity to act.

The criteria of content, process and empowerment (impact) were also used to analyze social innovation with respect to citizen science (Butkevičienė et al., 2021). From the perspective of engaged research, purpose, process and product may be criteria for analysis (Stanton, 2008).

Other aspects identified that help social innovation to achieve social change (according to Tardif and Harrison (2005) cited in Agostini et al. (2017)) are: the novelty and the nature of innovation, the objective of innovation, the innovation process, the relationship between structures and actors and innovation restrictions. Therefore, they suggested five dimensions of social innovation: transformation, innovative nature, innovation, processes and actors.

The model of the four layers of social innovation ecosystems (Kaletka et al., 2016) on the other hand, aims at understanding the complexity of the emergence of social innovations. It differentiates between four analytical layers: the context of roles, the context of functions, the context of structures and the context of norms. First, the context of roles refers to the stakeholders and beneficiaries in social innovation, their socio-demographic characteristics and their roles. This includes attitudes, skills, socialization, motivation and self-concepts, among others. Second, the context of functions encompasses the management and models of procedures, governance and business. This layer puts emphasis on the interlinkage and collaboration between actors and related network phenomena. Third, the context of structures layer depicts constraints and dependencies based on existing structures, such as institutions, political, economic or technological priorities. The fourth layer consists of the context of norms, i.e., the framework conditions and challenges posed by society. These are based on historical developments, the legal framework, ethical and professional standards and any other socially accepted standards that provide the basis for social innovation to occur.

Three levels of analysis and levels at which social innovation emerges are proposed by Cajaiba-Santana (2014), who differentiates between intra-social group innovations, inter-social group innovation and extra-group social innovations. The intra-social group innovations refer to basic values, beliefs, norms and conventions in a social group. The inter-social group innovations are based on various social groups that have a competitive or collaborative relationship, or both. The third level of extra-group social innovations is the macro-level of social systems.

The list in **Table 1** is not exhaustive and combines different aspects of social innovation. Nevertheless, it shows different criteria according to which translation in citizen science can be analyzed regarding its contribution to social innovation. Since not all these dimensions, layers, models, and criteria can be considered in this study, the focus of the discussion will be on agency, institutions, and social systems (Cajaiba-Santana, 2014) as well as four key elements of social innovation, i.e., satisfaction of a need, innovation of the solution, change of social structures and relationships as well as the increase in society's capacity to act (Portales, 2019).

Zooniverse

Zooniverse is a citizen science platform, which was launched in 2007 inviting members of the public to engage in its first project, namely Galaxy Zoo, in which volunteers classified images of galaxies. Due to the success of Galaxy Zoo, the Zooniverse team (from the United Kingdom and the United States) engaged in new research areas (beyond astrophysics and also beyond natural sciences), participant tasks (classification, annotation, transcription, etc.) and user interfaces. Zooniverse projects have a focus on the analysis of large amounts of data that cannot be done by researchers on their own. Zooniverse users can analyze research data in the form of video, audio or images directly on the Zooniverse project pages after being instructed on how to conduct the relevant analysis. Researchers provide tutorials or guidelines that help participants identify, classify and label data according to the researchers' requirements. Zooniverse is built on a domain model comprising the user, i.e., the volunteers participating in tasks; subjects, i.e., the elements that users are asked to annotate, transcribe or classify, such as light curves or museum specimen labels; workflows or tasks; classifications done by the volunteers; groups of subjects to allow for different displays on Zooniverse or different procedures of analysis; and, finally, a project, i.e., the individual citizen science project on the Zooniverse platform that is associated with subjects, classification and groups (Simpson et al., 2014). In 2019, approximately two million people had engaged in more than 150 Zooniverse projects to support hundreds of professional researchers in a variety of academic disciplines, ranging from physics and astronomy, climate science, ecology, biomedical research to the humanities. The volunteers' contributions in the form of tagging, marking or transcribing of images, videos and audio on the Zooniverse platform resulted in more than 160 peer-reviewed publications (The Zooniverse Team, 2019).

Zooniverse allows for the translation of individual Zooniverse project pages. Researchers can request a translation of their material on Zooniverse from (volunteer) translators all over the world (TTFNROB, 2014) to increase the number of participants contributing to their project.

The Zooniverse translation platform was also discussed as a tool for translator education, to familiarize translation students with translation platforms, their interfaces and workflows, including quality assurance (Michalak, 2015) and produce translations that are actually needed and publicly accessible.

Zooniverse was selected for the analysis because it offers translations directly on the website (compared to other citizen science platforms, where basic information about the project is provided only in English, and users can obtain further information by clicking the link to the actual project website). In comparison to other citizen science directories or project platforms, Zooniverse allows users to directly work on the Zooniverse platform without being directed to the project website or having to work outside Zooniverse. Zooniverse is therefore an interesting research object for translation scholars, allowing for translation flow analysis and social media analysis (Desjardins, 2021).

When the data for this study were extracted from the Zooniverse platform (in November 2020), 83 active projects were listed. However, only some of these projects offered content, i.e., information about their project or tutorials in English and (at least) one other language. Therefore, exclusion criteria were applied to the list of active projects on Zooniverse. Therefore, projects whose Zooniverse project page was only available in English were excluded. This reduced the final list to 17 projects. Another exclusion criterion would have been a regional focus of a citizen science project. This would be the case, for example, if a project in the field of biology or environmental sciences addresses only certain animal or plant species in a region. This regional focus would already exclude prospective participants outside this region. Thus, these projects would not address an international audience already by design and may not require translation. As assumed, this also held true for the projects on Zooniverse: Projects with a regional focus (in an English-speaking area), e.g., *Boston Phoenix, 1974!, London Bird Records, Nest Quest Go: Eastern Bluebirds, Notes from Nature: Plants of Arkansas, Snapshot Wisconsin or Scotus Notes: Behind the Scenes at Supreme Court Conference* were only available in English.

RESULTS

Translation receives considerable attention on Zooniverse. On the one hand, the Zooniverse website itself, i.e., the navigation and some contents are available in English and some other languages. Moreover, several citizen science projects listed on Zooniverse are available in more than one language. On the other hand, translation is also a topic discussed on the Zooniverse blog and in the general Zooniverse forums. On the Zooniverse Talk discussion forums, users recurrently ask for the translation of project pages or request translation features on Zooniverse. Zooniverse also provides a list of publications related to projects. Interestingly, this list only contains publications in English.

Since there is no translation policy, individual projects on Zooniverse decide on their own if their contents should be translated. However, the translations on Zooniverse are currently rather user-driven. "All translation effort comes from volunteers keen to bring the projects to their own communities" (Simpson, 2015). To become a volunteer translator for Zooniverse, users have to ask to be added as a translator to the project (indicating the target language). Then, they receive further instructions. If a volunteer translator wishes to contribute translations to a project on Zooniverse, the translation workflow itself therefore starts with contacting the project owner. Then, the project owner requests the Language option on Zooniverse, if not already enabled, and adds the volunteer as a Translator to the project. The project owner can select a language, in which the Translators work. The translations can then be published (and still be edited). This also means that if modifications are made in the English source text, these modifications are not simultaneously made in the target language. The comments on a project are not translated. Participants can however write their comments in any language, while it is recommended to GoogleTranslate them. The translators are primarily self-selected volunteers who are aware of Zooniverse or have already contributed to a Zooniverse project.

Interestingly, the topic of translation is mentioned on the Zooniverse blog predominantly in the year 2014. This was the year in which the Accessible Citizen Science for the Developing World project was gaining ground. In 2014, a call for volunteer translators on Zooniverse was issued. Within a short period of time, volunteer translators started to translate nine Zooniverse projects, starting in 11 languages. Especially volunteer translators from Spain and Germany were very active. The demand for translation was reflected by the usage figures. Between 2012 and 2015, the Zooniverse website traffic statistics showed that the percentage of users (who use a language other than English in their browser) visiting the English website decreased from about 65-70% in 2012 to 51% in early 2015. For individual translated project pages, this number was even 40% (Simpson, 2015). Since 2014, the topic of translation has not received much attention on the Zooniverse blog. Other research (Desjardins, 2021) also suggests that the translation features on Zooniverse are no longer further developed. However, in the Zooniverse forums, individual users are posing questions related to translation. A recent survey conducted to further develop the Zooniverse user interface revealed that the users still would like to have translations in more languages (Rother, 2018). In the discussion forums on Zooniverse, translation is a recurrent topic addressed by users. They are directing requests toward the Zooniverse team, e.g., introducing more multilingual Zooniverse features and more translation features. This demonstrates that the translation on Zooniverse is rather driven by the users, while no translation policy by Zooniverse is available (Desjardins, 2021).

The analysis of the Zooniverse projects showed that, from a total of 83 active projects, 66 projects were only available in

TABLE 2 | Zooniverse project pages available in at least two languages.

Title of the Zooniverse project	Languages	Number of languages
Every Name Counts	EN, DE	2
NestCams	EN, DE	2
Invader ID	EN, ES	2
American WWI Burial Cards	EN, FR	2
Beluga Bits	EN, FR	2
Galaxy Zoo: Clump Scout	EN, FR	2
Snapshot Hoge Veluwe	EN, NL	2
Plant Letters	EN, PT	2
Scribes of the Cairo Geniza	EN, AR, HE	3
Galaxy Zoo	EN, FR, ZH	3
Radio Meteor Zoo	EN, FR, ES, NL	4
Iuganas from Above	EN, Tutorials: DE, ES, FR	4
Penguin Watch	EN, CS, ES, FR, ZH	5
Chimp&See	EN, DE, ES, IT, FR, CS	6
Radio Galaxy Zoo: LOFAR	EN, DE, IT, PL, NL, SV, FR	7
Backyard Worlds: Planet 9	EN, FR, ES, IT, PL, PT, DE, JA	8
Disk Detective	EN, ES, FR, IT, PT, PL, DE, UK, JA	9

English, while 17 projects were available in at least two languages (**Table 2**), always including English (while one project included only tutorials in other languages). This means that 20% of the Zooniverse project pages were also available in another language in addition to English. The most frequent language was, of course, English, followed by French (11 projects), Spanish and German (7 projects each). Other languages that were also represented on Zooniverse project pages include Italian, Czech, Dutch, Swedish, Portuguese, Polish, Japanese, Chinese, Ukrainian, Arabic, and Hebrew. Fourteen of the seventeen projects were projects in the field of natural sciences while the remaining three projects can be assigned to the humanities.

The majority of the 17 projects that also included a language other than English were bilingual (8 projects), trilingual (2 projects) or offered information in four languages (2 projects). One project each supported six, seven (*Radio Galaxy Zoo: LOFAR*), eight (*Backyard Worlds: Planet 9*), and nine (*Disk Detective*) languages.

In addition, some Zooniverse projects also had a project website outside of the Zooniverse domain. This website or parts thereof were also available in other languages not used on Zooniverse, such as *Athena* (English and Dutch) or *Taranaki Mounga* (English and Maori). However, these projects were not included in the analysis since the focus was on the availability of other language versions on Zooniverse only.

From the point of view of localization, none of the citizen science project pages that were available in at least two languages, were localized, i.e., adapted to the relevant locale. First, locales or language varieties were not taken into account. The translations provided were in "French" or "Spanish", but the locale was not specified, such as French of France, Canadian French, etc. The same also holds true for Spanish, e.g., Spanish of Spain or Spanish in the Americas, as a rough differentiation. Second, the look and feel of the Zooniverse citizen science project pages were the same for all languages. This means that neither the colors, the navigation or the information flow, among others, were adapted to the relevant culture. Only the text on the pages was translated. However, localization may run counter to the principle of ensuring a common look and feel of the entire Zooniverse platform, and, thus, of all projects. Moreover, as mentioned before, localization already needs to be considered during website design. Interestingly, the *Scribes of the Cairo Geniza* project has a design that deviates from the other projects on the Zooniverse platform. In addition to English, this Zooniverse project page is also available in Hebrew and Arabic, i.e., languages that are usually written and read from right to left. Whether the translation into these languages necessitated the deviating web design or if there are other reasons, such as reasons related to the display of the material and the completion of the tasks, would need further investigation.

Another observation is the selection of languages in which the Zooniverse project pages were translated, showing a clear tendency of languages with a higher status or high resourced languages, such as German, French or Spanish in addition to English. Only two projects offered translations into Mandarin Chinese, even though this language has the highest number of first-language speakers, and thus, a large pool of potential participants. In some cases, the selection of the languages may also depend on the topic of the project itself, such as in the *Scribes of the Cairo Geniza* project, which invites volunteers to work on pre-modern and medieval Jewish texts that had been hidden in Cairo for centuries. Therefore, the use of Hebrew and Arabic may result from the research objects themselves.

From the perspective of terminology, the analysis of the Zooniverse projects showed that the use of domain-specific terminology was reduced to a minimum. If domain-specific terminology was used, it was either explained directly in the text where it occurred or additional information was provided, such as in the FAQ or directly in the text. The project *Disk Detective*, for example, used the FAQ to briefly explain acronyms or proper names of tools and resources. The project *Scribes of the Cairo Geniza* explained terms directly in the text, e.g., the term "geniza". The number of domain-specific terms was rather low, which made the texts comprehensible to a non-specialist audience.

DISCUSSION

In the following, these results are related to cultural differences that are negotiated through translation as well as translation validation in the case of crowdsourced translation for citizen science projects. Furthermore, they are embedded in a broader context based on the following basic criteria of social innovation: agents, structures and social change. The latter is discussed from the perspective of the transformative potential of translation in and for citizen science.

Crowdsourced Translation

The translations on Zooniverse are a combination of both solicited and unsolicited translations (Jiménez-Crespo, 2013). Solicited translations, i.e., an organization issues a translation call to a community, could be predominantly observed in 2014, connected to a project aimed at increasing the accessibility of Zooniverse. Today, Zooniverse translations are rather non-solicited since self-selected users organize and complete translation tasks themselves without being requested to do so. However, Zooniverse provides the related infrastructure, i.e., a translation platform.

Zooniverse is thus also an example of crowdsourced translation where "translation consumers are increasingly becoming translation producers" (Cronin, 2010). This has also far-reaching implications for translation theory, which has been characterized by production-oriented models. These models assume that an agent produces translations that are consumed by an audience. Crowdsourced translation, however, means that the actual audience produces the translation on its own. Thus, they are no longer unknowable recipients of translation, but they are becoming active translation agents, i.e., producers or prosumers (Cronin, 2010). Moreover, since plural points of view and various modes of interaction are taken into account, the translation process and translation decisions can become more transparent (in comparison to translations done by professional translators). However, in crowdsourced translation endeavors quality assurance does usually not follow the principles found in the translation industry. In the translation industry, for example, the standard ISO EN 17100 "Translation services–Requirements for translation services" (ISO, 2015) specifies that translations are produced by professional translators (having a relevant university degree and/or experience) and that a second bilingual person revises the translated version (four-eye principle), among others. Moreover, in the translation industry quality evaluation and estimation metrics are heavily applied, such as BLEU for machine translation, the Multidimensional Quality Metrics (MQM), the quality assurance model by the former Localization and Internationalization Association (LISA QA Model) or SAE-J2450, which was initially developed for the automotive industry, but is also applied in other contexts. While these quality metrics enjoy popularity in the translation industry, these are not very common in the field of crowdsourced translation, including the Zooniverse translation platform. Reasons for this might be that their use requires some training and experience. Additionally, inter-annotator agreement has to be considered when evaluating the quality of translations with these metrics.

This shows that we can draw interesting parallels between crowdsourced translation and citizen science. Crowdsourced translation (and citizen science alike) require project and community management. Three important steps when crowdsourcing translation can be identified: a plan for crowdsourced translation, community building and support as well as the creation of a collaboration platform (Dunne and Dunne, 2011). When starting a platform for crowdsourcing translations (similar to citizen science) it is crucial to identify the community and to know their motivations to meet their expectations. Zooniverse already identified their users' need to contribute to the translation of the platform itself and of individual project pages and provided a translation platform.

According to the literature, the recommended look and feel of a collaboration platform include a landing page providing an overview of projects, allowing for account management, informing about the terms and conditions, tasks and roles and facilitating the recognition of members, etc. After registration, the landing page should provide an overview of project management and the user role, such as translator, the tasks assigned, monitoring, and the type and volume of the items to be localized. To collaborate successfully on a crowdsourced translation project, collaboration needs to be supported with shared workspaces and resources, such as terminology management or glossaries, features for revision or voting on translations, style guides, a chat function or testing of localized versions. Moreover, the user interface for the actual translation should allow for terminology search, translation memory lookup and review. It is important that the volunteer translators do not have to handle code, but just the content of the page which needs to be localized (Dunne and Dunne, 2011).

Although the translations on Zooniverse are strongly user-driven, Zooniverse may also prepare a translation policy, appoint a project manager for the crowdsourcing of translations and define individual goals, such as increasing linguistic diversity on the platform. Another parallel between crowdsourced translation and citizen science is that users have to receive clear task descriptions, such as which contents to translate, how to manage terminology and how to ensure quality (e.g., consistency, accuracy). Moreover, the ownership of the results should be clarified in advance, e.g., if the translators have to agree to any terms and conditions. Additionally, crowdsourced translation requires constant community management, and thus communication (about task distribution, feedback on translations, quality evaluation, process management, acknowledging the contributions of the volunteers, etc.). Community management necessitates transparency, building of trust, opportunities for mentoring so that expert users can help novice users. Moreover, it requires a clear definition of roles and processes to manage the expectations of all persons involved. In the case of Zooniverse, the volunteers involved in the translation project receive support from the organization, either from the Zooniverse team or the leaders of individual citizen science projects on Zooniverse. Moreover, documentation on how to use the translation platform would benefit the users, e.g., how translation processes are defined and how quality is assured. Depending on the motivation of the users, the project managers can also acknowledge and recognize the contributions of the volunteer translators, either by issuing certificates, providing opportunities for learning or competence development, highlighting individual contributions, using leader boards, etc. Regarding the recruitment of volunteer translators, Zooniverse already has a community (of citizen scientists) of which some members are interested in producing translations for Zooniverse as well. Another option to recruit volunteer translators would be to extend the reach to potential volunteer translators who are not already familiar with Zooniverse.

The accuracy of the translations on Zooniverse has an impact on the quality of the tasks completed by the citizen scientists (if they rely on the translated instructions). The translations have to ensure that the participants in citizen science projects who use the translated version of a project's page fulfill the tasks as intended by the researchers. To ensure that the source and the target text have the same meaning, an option would be to involve professional translators for quality evaluation, consistency checks regarding terminology (or style guide, if any) and integration with the source content.

Another option is multiple revision steps or community voting. The quality of crowdsourced translations may thus be assured through peer review, such as voting systems to decide on the "best" translation (Jiménez-Crespo, 2013). A third, more extensive option would be the validation of translations as applied for research instruments used in cross-cultural research endeavors.

Validation of Translations

In the translation industry, the aforementioned quality metrics are applied to ensure the quality of translation, including accuracy, fluency, terminology, style, locale convention, etc. [in MQM (Lommel et al., 2014) terms]. Another approach (translation validation) can be found in cross-cultural research. Here, the translation of research instruments, such as questionnaires, undergoes several evaluation and validation steps to ensure cultural adaptation and equivalence in the target culture. Generally, translation validation requires various steps of instrument translation, cultural adaptation, content validation and equivalence assessment. These are important to ensure that the meaning of the items, the dimension integrity and validity are constant across cultures. Different equivalence criteria for cross-cultural research with instruments have been proposed. These criteria are, for example, content equivalence, semantic equivalence, technical equivalence, criterion equivalence and conceptual equivalence. These should ensure that the contents of the items are relevant to the aspects of each culture that are studied, that the meaning of the items is the same, that the method of assessment is comparable in the cultures, that the interpretation of the variable measurement are the same according to the norm in each culture and that the instrument measures the same (theoretical) construct in each culture. To ensure instrument equivalence, both qualitative and quantitative methods can be used and combined, including forward and reverse translations, expert evaluation, feedback questionnaires, pilot testing, participant review or cognitive interviews. According to this, the translation validation can consist of three phases and seven steps. The first phase, the instrument translation encompasses the steps: 1) instrument review and translator selection, 2) forward translations with synthesis, 3) reverse translation with reconciliation. The second phase, cultural adaptation, comprises 4) pre-test, 5) cognitive interviews, 6) research team review with item revision. The third phase, content validation and equivalence evaluation, consists of 7a) subject-matter expert evaluation and content validity as well as 7b) subject-matter expert evaluation of equivalence (Palmieri et al., 2020). The result should be an instrument in the target language that "asks the same questions, in the same manner, with the same intended meaning, as the source instrument" (Palmieri et al., 2020).

In different rounds, the cultural adaptability, the clarity of the translation, the cultural relevance and readability are assessed by different agents in the process. The cognitive probing step has a strong focus on terminology. Especially terminology may cause difficulties because it is embedded in a certain cultural system that relies on different categories, such as different terms for private and public hospitals (Palmieri et al., 2020).

Translation validation for cross-cultural research has a focus on equivalence, cultural applicability (adaptation) and cultural relevance, including readability and cultural adaptation for content validity. This should ensure that the instructions given to participants are interpreted in the same way in different cultures. In short, the translated instructions should not change the results. On Zooniverse, there is no translation validation according to the process described above. The translations on Zooniverse are not back translated and there is no systematic evaluation if the translations impart the same meaning as the source text. On Zooniverse, the translations can be revised after they have been published. As a result, users may see different instructions on translated project pages. These can be seen as reasons to question the accuracy and reliability of the translations since this may have a (negative) impact on the way how the participants complete tasks, and thus, jeopardize the research results. However, this has to be assessed in view of the fact that some Zooniverse users who contribute to a project that is only available in English reported that they translate the Zooniverse project pages and instructions with freely available machine translation systems into their language. This shows that researchers asking volunteers to complete citizen science tasks on Zooniverse cannot control how participants who do not use English as a preferred language interpret the task and if they use machine translation systems to understand the instructions. Since the quality of translation of freely available machine translation systems differs significantly between language pairs and domains, it cannot be guaranteed that the machine-translated text imparts the same meaning as the source text and that the machine-translated instructions are accurate enough so that the participants fulfill the task correctly (as intended by the researchers).

Although the translations on Zooniverse are not validated (according to the principles presented above) and can just be revised, they are nevertheless an important step of social innovation in citizen science. This echoes social innovation literature that states that grassroots innovations (in contrast to top-down innovations) that provide bottom-up solutions and offer strategies for cultural change can effectively respond to local concerns and contexts (Grimm et al., 2013).

While translations done by volunteers are sometimes criticized for not being as accurate as those of professional translators, volunteer translators usually take their tasks seriously. Furthermore, the quality of the translations is sometimes thoroughly evaluated by the community itself. Moreover, in forums, on advice pages or through mentoring, volunteer translators provide guidance and support to others. "These volunteers, unlike their professional counterparts, are actively encouraged to account for cultural distance and to intervene on the text, and are fostering communication across language and cultural divides" (Katan, 2016). Therefore, translations done by volunteers who are also participants in these citizen science projects would lead to a more accurate translation (compared to machine translation) since the volunteer translators have already participated in the project and are aware of the tasks themselves. In accordance with other crowdsourced translation activities, in which the users are translating the product or service themselves, the volunteer translator community on Zooniverse has already acquired profound knowledge of the project, its topics and tasks since they accumulated experience while completing the tasks themselves. This is in accordance with the literature that states that organizations engaging in crowdsourced translation with their users may draw on the knowledge and motivation present in their users. This helps increase the suitability and acceptability of their products and services or win the loyalty of customers (Massardo et al., 2016) (or participants in the case of citizen science).

While crowdsourced translation on Zooniverse has several benefits, it also raises issues of cultural differences and how far cultural differences can be bridged by translation.

Cultural Differences

Different cultures do not only experience and see the world in many different ways but also make sense differently. Cultures differ in many aspects, including differences in value judgements (ascribing different values to things), differences in existence of abstract things (e.g., using abstract nouns for non-physical things), differences in the existence of concrete things (multiple words for snow in some languages), differences in relationships between things, differences in reason and thinking and differences in seeing things. Also, abstract nouns vary significantly between cultures and, therefore, translations may not capture the meaning equivalently. In some cultures, certain concepts may not exist at all. Therefore, speakers of one language see different things and differentiate things differently (group them into other categories). Moreover, within a culture there are subcultures organized around lifestyle, age, geographical location, and work, etc. These subcultures, again, experience and make sense of the world differently. This means that values, abstract systems, forms of reasoning and logic may also vary considerably within a culture (McKee, 2003). Thus, translation means to negotiate cultural differences. Therefore, also obstacles can arise from translation. One of these obstacles is (culture-bound) terminology.

Terminology

Different schools of terminology exist. While traditional terminology defines terminology as the entirety of concepts and their designations in a specialized area (RaDT, 2017), socio-cognitive terminology starts from units of understanding (that are often characterized by their prototypical nature) that depend on human language (and understanding) (Temmerman, 2000). The main difference between these two paradigms is that the first is objectivist, while the latter is experientialist.

In the present study, terminology is defined according to an ISO standard. The main elements in terminology are concepts and terms within a domain. A domain is a sphere of knowledge, subject field or activity that has its own social context, specialized culture and linguistic characteristics (ISO, 2002). Examples of terminologies include tax law, ornithology or precision medicine. Terminology facilitates communication between specialists and plays a crucial role in knowledge transfer and knowledge management (also across languages). While concepts are mental representations of phenomena and objects (units of thought) within a specialized field or context (ISO, 2002), terms are the linguistic expression of concepts. For example, the term "mouse" may either refer to the concept of the animal (mouse) or the concept of the computer mouse.

Cultures may have different knowledge and thus different knowledge systems. Similar to translation (multilingual) terminology tries to find equivalences of concepts in other languages. However, there may be fundamental differences between cultures. This is also at the core of socio-cognitive terminology, which elaborates on the "interaction between the world, language, and the human mind" (Temmerman, 2017). Languages reflect how humans understand, perceive and conceptualize the world. Since human understanding and new concerns in society evolve over time, languages and thus also terminology change (Temmerman, 2017). If there is a paradigm shift or revolutionary change, the transition period is also characterized by concept changes and term changes (Kristiansen, 2014).

There are "different degrees of cross-linguistic equivalence" (Temmerman and van Campenhoudt, 2014). On the one hand, there may be cultural uniformity in some domains, such as in accounting, while in other domains, such as law, there is a clear culture boundness (Temmerman and van Campenhoudt, 2014). Therefore, not all concepts are difficult to transfer from one culture to another, but especially those that are strongly culture bound (Kristiansen, 2014). This culture boundness is based on the assumption that cultures shape the human brain. Therefore, human cognition differs between cultures, even between closely related cultures: "our modalities of experience and our perception cannot be separated from the environment where we live and our previously stored experiences" (Faber and León-Araúz, 2014).

Bias and Multilingualism

The topic of translation is rarely problematized in the English citizen science literature. It seems that many citizen science projects assume that the participants are proficient in English. According to a study by Desjardins, (2021), explicit or implicit Anglocentrism, including epistemologies and computer programming, is also an issue in citizen science. Moreover, (even) if there is translation, it usually enriches English-language scholarship, i.e., the translation flow (knowledge transfer) is directed from a language into English. With regard to online citizen science, practices and structures have been addressed as reinforcing Anglocentrism, which leads to inequities and asymmetries when exchanging (scholarly) knowledge and cultural capitals. However, the (potential) participants in citizen science projects are characterized by diversity, such as language, culture, and education, etc. A recent study analyzing the translations and localizations on Zooniverse demonstrated that in 2019, nine projects, all from the natural sciences, were translated, i.e., the Zooniverse project pages were available in at least two languages or had translation features. Since translation considerations are usually not taken into account when designing a citizen science project on Zooniverse, this may reinforce epistemological biases, which may lead to limitations for pluralism and diversity. This study came to the conclusion that there is "limited linguistic diversity and generally Anglocentric modes of knowledge creation and dissemination" (Desjardins, 2021). Authors affiliated with Zooniverse are aware of some of these biases as well: Zooniverse is biased toward English-speaking volunteers who use browsers with high-speed connections. This raises issues of accessibility and international participation. Therefore, the former project Accessible Citizen Science for the Developing World aimed at improving the Zooniverse translation tools and reaching more diverse participants (in addition to increasing the accessibility of the Zooniverse project builder) (Simpson, 2015).

Therefore, the question arises whether a citizen science platform launched in a multilingual environment, compared to Zooniverse, would consider multilingualism and translation already from scratch. Since the EU-Citizen.Science platform (eu-citizen.science) was launched in such a multilingual context, it may support different languages and translation features by design.

The EU-Citizen.Science platform (EU-Citizen Science, 2020) emphasizes that citizen science should become a means for the democratization of science. Its mission is to share knowledge across networks, including researchers, policymakers, participants in citizen science projects, practitioners and society in Europe. Since the platform serves as a knowledge hub and community hub in Europe, we may draw the conclusion that this knowledge is made accessible and exchangeable in different languages (also by means of translation). Especially, "Objective 3: Empower" emphasizes that a wide range of stakeholders can become citizen scientists, start and implement citizen science projects and approaches in a professional way. "Objective 4" addresses new ways of participatory governance and a stronger link between citizen science and policy, whereas "Objective 5" aims at citizen science becoming mainstream in public engagement, education and science communication. To reach these objectives, translation or localization are important, because science communication, education, the implementation of citizen science initiatives and policymaking in Europe are usually taking place in a language other than English.

Interestingly, EU-Citizen.Science (as at January 5, 2021) offers content predominantly in English, including announcements of news or events, forum discussions and blog posts. Among the 87 resources available on the platform, some are available in languages other than English. Among the 19 training resources (although the language filter is enabled) none are available in a language other than English. However, the teaser video introducing the EU-Citizen.Science platform is available in 12 languages. Although the overview of citizen science projects lists projects from all over Europe and beyond, the projects either bear English-only names or provide an English explanation of the original title in brackets. On the individual project pages on EU-Citizen.Science, 147 projects (as at January 5, 2021) are briefly described and tagged in English. The individual project websites themselves (not under the EU-Citizen.Science domain) also give information in languages other than English. Before drawing conclusions about Anglocentrism and an underrepresentation of multilingualism on EU-Citizen.Science, it is important to bear in mind that the EU-Citizen.Science platform was launched only recently. However, there was no information available whether it will feature and promote multilingualism and translation in the future.

The efforts made by Zooniverse and EU-Citizen.Science to increase linguistic diversity and knowledge exchange by means of translation deserves recognition. In contrast to other internationally visible citizen science platforms, Zooniverse and EU-Citizen.Science are supporting languages other than English and the localization of their content. This multilingualism and translation are ingredients for social innovation in citizen science.

Translation and Social Innovation in Citizen Science

Social innovation can refer to both, the process and the outcome. Social innovation, thus, must not necessarily aim at a target. The process itself can be an innovation outcome as well. Through co-production, resource sharing and cooperation, new social relations may emerge between previously unrelated or uncooperating stakeholders. The social capital can increase by improving a society's capacity to act and by helping create resilience and sustainability in societies (Grimm et al., 2013).

Agents

Social innovation is characterized by seeking social change and a focus on (societal) values, the promotion of cooperation among actors and the improvement of relationships. This is in contrast to economic innovations, where the commercial benefits and competition among actors are dominant (Portales, 2019). Social innovations often result in novel social relationships between organizations and individuals from different walks of life. The process of co-creating solutions to social needs can thus lead to transformative change (Grimm et al., 2013). This co-production of solutions means that actual users also make decisions, which is also the case on Zooniverse. However, these agents are also subject to different merit (and value) systems that may be conflicting. Therefore, the interplay between policy, cultural norms and individual capacity should be considered. This is also the reason why measuring social value can be problematic (Milley et al., 2018).

Social innovation requires participation and engagement from a wide diversity of actors, thereby requiring individual citizens to assume responsibility (Grimm et al., 2013). Citizens become active participants in collective decision-making. This responsibility is based on engagement and empowerment (Nicholls et al., 2015).

This is also the case for Zooniverse translations that are predominantly initiated proactively by the citizen scientists themselves who wish to bring the projects to their cultures. Moreover, social innovation is often spurred by individuals. They did not only voice a (social) need (which was also reflected by a Zooniverse survey (Rother, 2018)) but are also, to a certain extent, co-creators since they are directly involved in the development or further improvement. In the case of Zooniverse, this leads to a new relationship between the researchers, the Zooniverse staff and the citizens. However, the diversity and number of stakeholders that is usually required in social innovation processes is rather low. Different specializations, including competences and resources, need to be combined to arrive at social innovations. The driving forces, or agents, in social innovation processes have been grouped into different categories by different authors. One of these categorizations is the triad of public bodies (public), private companies (private) and NGOs/NPOs (civil society) who identify problems, provide resources and infrastructures that complement each other and create synergies (Nicholls et al., 2015; Butzin and Terstriep, 2018).

Other authors define individuals, organizations and social movements as key agents in social innovation processes (do Adro and Fernandes, 2020). Social innovation would, thus, require that every member of the community is actively involved in the innovation process. This is also reflected in funding schemes of the European Union that emphasize the role of citizens in research and innovation (processes). Since these citizens speak different languages, translation is an essential component of active participation. Only if members of the public understand the material given to them or what is expected from them, they can be agents of social innovation. Since many projects provide information primarily in English, they may exclude a large proportion of the agents required for instigating change. Therefore, translation can help remove the language barrier and any misunderstandings that may arise due to a lack of language proficiency if information is only provided in English. When highlighting the agents in social innovation, it is also important to address the inclusion or exclusion of certain agents in the process.

In citizen science, the main agents of social innovation would be the researchers, the participants, and in the case of translation, the translators (and platform developers). However, these agents are embedded in communities, organizations and institutions. Therefore, also research institutions, funding bodies, the professional and personal environment of a person, etc. play a role.

Furthermore, translation also plays an important role for Zooniverse, which states: “Our goal is to make it easy for anyone to contribute in a valuable and meaningful way to real academic research” (The Zooniverse Team, 2019). By overcoming language barriers through translation, it is easier for ‘anyone’ to contribute to academic research.

“One of the defining features of social innovation is that it provides insights and develops capacity and soft infrastructure (intangible assets such as know-how, intellectual property, social capital, etc.) that endure and can be utilized by other sectors and forms of innovation” (Grimm et al., 2013). According to this, the translation on Zooniverse helps develop capacities. The volunteer translators gather know-how on translation and the use of technology, i.e., the translation platform. They create their intellectual property through translation. Moreover, the code for the Zooniverse translation platform is available as open-source code on GitHub (https://github.com/zooniverse/Translator/), which makes it re-usable by others.

A peculiarity of the translation of citizen science project materials is the comprehensibility for a non-specialist audience. Usually, the authors of the source texts in citizen science projects already consider the necessity to re-phrase, generalize or simplify texts and avoid using terminology that the audience may not understand. Therefore, also the translation of these texts has to strike a balance between domain-specific knowledge and general comprehensibility, between the loyalty to the disciplinary discourse and the loyalty to the readers.

On the Zooniverse platform, researchers do not only ask participants to volunteer for research but also translators to voluntarily provide translations for their Zooniverse project pages. This means that researchers draw on the effort and resources of two (different, but partially overlapping) groups of volunteers who want to contribute to the generation of a greater common good (which is also a basis of social innovation). If these groups are considered agents in social innovation, they are part of the process of innovation generation and diffusion. This will be discussed in the next sections.

Structures

The structures relevant in the current analysis range from the research landscape in general and the citizen science landscape in particular, to social developments, legal requirements and various other framework conditions. Since the focus of this analysis is the role of translation in citizen science, the following section concentrates on the citizen science landscape.

While translation of citizen science projects and material can help foster social innovation, translation is also embedded in framework conditions (structures). These framework conditions are, among others, the citizen science landscape itself. There are numerous citizen science project platforms and manifold citizen science projects all over the world. Especially if citizen science projects aim at addressing a global audience, they basically compete for the same participants. However, if these citizen science projects address different topics and offer different tasks to prospective participants, they may serve different motivations and interests of the volunteers so that they would not compete for the same participants per se. To illustrate this with projects from the Zooniverse platform: Users may select a project to which they wish to contribute based on the topic of the project and the tasks they have to fulfill. If participants are rather interested in biology, they may choose a project where they can engage in an activity with animals or plants. Then, they may select between projects based on a species that is more appealing to them. Zooniverse offers several projects from natural sciences, and biology in particular. Users can choose if they want to address, e.g., biodiversity in general (e.g., *Taranaki Mounga*) or animals in general (e.g., *eMamma*l). Additionally, they may select from different species. If persons are interested in animals, they can choose between penguins (*Penguin Watch*), birds in general (*NestCams*), chimpanzees (*Chimp&See*), beluga whales (*Beluga Bits*), etc. Despite of the topic, they may also choose between different tasks. If they are interested in astronomy, they can select from various projects, e.g., *Astronomy Rewind, Aurora Zoo, Bursts from Space, Galaxy Zoo, Planet Four: Ridges, Planet Hunters Tess* or *Spiral Graph*. The volunteer tasks in these projects range from contributions to the creation of a database of astro-referenced old astronomy images and measuring the curvature of spiral arms in galaxies to searching for undiscovered worlds or discovering networks of polygonal ridges. Some of these tasks are certainly more appealing to a certain group than others leading to a self-selection of participants.

While the topics and the tasks of citizen science projects may be seen as "barriers" to some groups of potential volunteers, another obvious barrier on the Zooniverse platform is the language barrier. People who are not confident in using English, or using scientific terms in English, etc. may be rather attracted to citizen science projects offering a website, training material, publications, etc. in their preferred language.

In this case, translation can help overcome this language barrier and may attract users to the platform that would otherwise not visit the platform or would not pay any attention to a certain citizen science project (if information is only available in English). Therefore, citizen science projects offering their project materials and tools in a language other than, or in addition to English, may draw from a larger pool of potential project contributors. Therefore, they may have a competitive advantage over citizen science projects that provide information in English only. Similar to economic interests, when companies localize their products to maximize profit and reach currently unreached target markets, citizen science projects may increase the number of their participants, by offering translated or localized versions of their websites and their tools. Through this translation or localization, they may either gain a competitive edge over their "competitors", i.e., other citizen science projects or increase the number of potential volunteers by reducing language barriers. However, social innovation is not so much about having a competitive edge but rather about satisfying a yet unsatisfied human need.

Another framework condition in the citizen science landscape is the financial support for both the launch of projects and the maintenance of projects in the long term. Moreover, the persons involved in citizen science require appropriate incentive systems, such as institutional recognition of citizen science activities as proposed with the social impact indicator in addition to awards, prizes or privileges for the persons involved in citizen science (Schäfer and Kieslinger, 2016). The emergence and further development of citizen science in the past years can also be attributed to the framework conditions found in academia increasingly characterized by reliance on external funding, research questions requiring large amounts of data and the need of research to address societal challenges, the latter being enshrined in the third mission paradigm of universities. Citizen science may also be seen as serving a societal need. It can help combat distrust in science among society, align research with real-world needs and societal challenges and contribute to the empowerment of citizens.

Social Change: The Transformative Potential of Translation in Citizen Science

This section sheds some light on the role of translation used in citizen science projects and the ways of how translation can foster social innovation through citizen science activities. As mentioned before, social innovation is embedded in a social structure and requires the interaction between a variety of actors. The social innovation process is an open process and social innovators are usually deviating from prevailing paths, rules, routines and models. Therefore, altered social practices drive transformative social change (Howaldt et al., 2016). While it is already established that citizen science itself is a means of departing from established routines, models and rules in academia – and, thus, a form of social innovation (Butkevičienė et al., 2021), this transformative potential of translation in and for citizen science is less obvious. One of the reasons for this is certainly the practice of translation itself which looks back on a long tradition. Therefore, from the innovation dimension perspective, translation itself is nothing new or innovative. However, as described above, translation can trigger change. An example of this is the notion of "citizen science". The concept of citizen science, i.e., the act of engaging members of the public in conducting (certain steps in) academic research on their own, may not exist in certain languages, e.g., because citizen science is not practiced. On the other hand, if the concept of "citizen science" already exists, a language community may already use a term in the respective language for it. The third option would be that the concept of "citizen science" is currently being introduced. This usually means that there is no term in the relevant language available for the practice of "citizen science". Then, there are two options. First, the English term "citizen science" can be incorporated as a loanword into the relevant language. For example, in Austria "Citizen Science" is also used in German (the only adaptation being the capitalization of the words in accordance with the writing of nouns in German). The second option, which was adopted in Germany, was a calque, i.e., a loan translation, resulting in, e.g., “Bürgerwissenschaft”, being a word-for-word translation of the term “citizen science”. On the one hand, this example shows that translation, in its broadest sense, can help change the mindset as well as established practices. On the other hand, it also demonstrates the importance of localization, and in this respect intralingual localization. Although German is the official language in both countries (Austria and Germany), different ways of introducing the concept of “citizen science” were chosen. Similar to social innovation, this is rooted in certain framework conditions. One of these framework conditions in this example is the use of Anglicisms in the German language, where the language community in Austria is more willing to borrow words and phrases from English compared to the language community in Germany. While the use of the calque “Bürgerwissenschaft” may result in a better comprehensibility of the term among the general public, the loanword “Citizen Science” on the other hand can emphasize the novelty of the concept while having only one meaning and being basically free of (unintended) connotations. However, sometimes the concept of the loanword, i.e., the meaning of “citizen science” may change when being introduced to another language. This can be detrimental when persons from the language community from which the concept “citizen science” originated and persons from the language community using the loanword with another meaning use “citizen science” in a conversation. While the term is the same, i.e., “citizen science”, the meaning (the concept behind it) is different, which may cause (serious) misunderstandings. To sum up, the introduction of concepts (for example, in the form of loanwords or calques) from one culture to another may introduce alternative social practices that are at the core of social innovation.

Turning now to the ability of translation to instigate this change based on the assumption that social innovation encompasses (profound) changes in complex systems, such as constructs, institutions, relations and behaviors (Antadze and Westley, 2012).

First, translation is a means for knowledge transmission. Although knowledge can take various forms and can be transmitted by different means, language is the primary means to transmit knowledge. Since language barriers can also become barriers to knowledge transmission, translation plays an important role when it comes to knowledge transmission between languages. Translation, thus, can give access to information, knowledge, products and services, practices, etc. as well as different ways of thinking and interpreting the world. These knowledge and social practices may instigate change in the receiving culture by introducing new elements in the target culture. Translation is thus not restricted to language and texts, but it is a social and cultural activity (Bachmann-Medick, 2013). This linguistic and cultural diversity is crucial to find solutions to societal challenges. Nevertheless, translation also is an act of negotiation and mediation between different cultures and requires interpretation from the translator.

Translation is a form of appreciation: an appreciation of the source text, on the one hand, and appreciation of the participants in citizen science projects, on the other. The appreciation of the source text means that the effort of translation alludes to the fact that the text has a certain value, and its content needs to be disseminated in other languages. Translation also means the appreciation of volunteers in citizen science projects, since it is a welcoming and appreciative act to receive information in a preferred language. Additionally, translation helps to overcome language barriers and misunderstandings that may arise if participants have to use a language in which they are not fluent, such as English on Zooniverse.

Second, translation is a driver of change. Translation has the power to bring about change. This can be either a turn for the better or a turn for the worse. While translation can be used to exert power, to manipulate people or to impose certain ideologies, it can also have a positive impact by enriching the receiving culture. This positive impact may range from empowerment, representation of minority groups to negotiations to resolve conflicts in a peaceful way, new interpretations and the acknowledgment of diversity (Tymoczko and Gentzler, 2002).

Third, “translation” is a term that is also used beyond its own discipline, namely beyond translation studies. Translation is either used as an analogy or as a means of argumentation by scholars from other disciplines. Translation, thus, has an impact on theories and discourse beyond its discipline (Woodsworth, 2013). This translational turn in various academic fields has led to the enrichment of these fields with findings, methodology and approaches from translation (studies). Translational approaches consider contexts, cultures, differences, mediation, and connections, etc. and help negotiate differences, assess misunderstandings and show power asymmetries (Bachmann-Medick, 2013).

Fourth, translation helps to overcome language barriers (and cultural barriers). As the definition of translation already suggests, it aims at enabling communication between languages and cultures. Mutual understanding across languages and cultures is therefore key.

Fifth, translation also means adaptation (also referred to as localization). According to the functionalist theories in translation studies, translation has to fulfill a purpose and this purpose influences the translation strategies and the final outcome. This is closely related to localization studies. Localization studies differentiate between globalization, internationalization, localization, and translation. In localization studies, localization is defined as the adaptation of a product (or service) to a target market, i.e., a locale. This means that a product’s content, functions and look and feel are adapted to the requirements of the target market. In comparison to translation (according to localization studies), localization encompasses the adaptation of linguistic and non-linguistic elements, while translation only focusses on linguistic aspects of a product (or service) (Drewer and Ziegler, 2014). Thus, a well-localized product does not only meet the (cultural) expectations and preferences of the target audience (i.e., the content is culturally sensitive) but also the (legal and technical) requirements of the target market (Dunne and Dunne, 2011). This is briefly illustrated with a website of a citizen science project. Localization thus means that not only the text on the website is adapted (translated) but also the images, colors, functionalities, the navigation bar or the sequence or flow of information, symbols or fonts so that the localized website has the look and feel of an "original", i.e., a locale-specific website. In certain cases, it may be even necessary to change the name of the project if the name of the project evokes undesired connotations in the target locale. This demonstrates the importance of cultural embeddedness and culture-bound terminology.

A special form of localization is intralingual localization, i.e., the localization between different varieties of the same language. Typical examples for locales are American English, British English, South African English, etc. Here, the characteristics and conventions of the target audience, i.e., speakers of the same language who use a different variety within this language, are taken into account.

Referring back to Zooniverse and the differentiation between internationalization, localization and translation. While localization creates a culturally sensitive product that meets the requirements of the target locale, internationalization lays the foundation for successful localization. In localization studies, internationalization refers to the design of a product that allows for the adaptation to the target market, i.e., allows for localization. For a citizen science project platform, this means that already in the website development stage, localization aspects are considered, such as bidirectional reading, change of colors, support of other fonts and character sets, e.g., Asian script, audio and video output, other units of measurement, such as date and time, decimal separators, symbols and text expansion for the translation into languages that are usually longer than the source text.

Sixth, when used as a metaphor or analogy, translation in the context of citizen science can also mean that citizen science itself is a translation (exercise) and a means to introduce and translate knowledge or academic principles to non-professional researchers as well as a means to introduce and translate social innovation.

Social innovation is characterized by the interrelatedness of social and institutional structures and agency (Cajaiba-Santana, 2014). Translation can permeate all these agents and structures and support their role in the process of social change as part of social innovations. This is also supported by the definition of social innovation by the Center de Recherche sur les Innovations Socials (CRISES) as cited in Agostini et al. (2017): Social innovation is "a process initiated by social actors to respond to a desire, a need, to find a solution or to seize an opportunity of action to change social relations, to transform a frame or propose new cultural orientations to improve the quality and community living conditions". Translation has the potential to transform (cultural) orientations since it enables the communication between cultures.

When considering the various criteria derived from the social innovation literature, with a focus on the four key elements: "satisfaction of a need, innovation of the solution, change of social structures and relationships, and the increase of society's capacity to act" (Portales, 2019), the (crowdsourced) translation of citizen science project information and websites satisfies a need, i.e., the need of volunteers who want to access products, services and information in their preferred language. It is important to bear in mind that the selection of the languages in which a citizen science project website is translated (or preferably localized) should be in line with the objective of the project. Often, the selection of the languages reflects their social capital. Regarding the "innovation of the solution", translation is not innovative per se since it looks back on a long tradition and has been used in various contexts. Nevertheless, translation in and for citizen science can change social structures and relationships and help increase a society's capacity to act.

On the question of the dimensions of social innovation (Moulaert et al., 2005) in relation to translation in citizen science, we may differentiate between the content (How does translation in citizen science satisfy social needs?), the process (How does translation change social relations in citizen science?), and empowerment (How does translation increase capabilities and access to resources?).

Social innovation (and partly also translation) is usually considered as an improvement or a positive change. However, innovations (and also translations) may have unintended consequences or externalities. While some stakeholders may benefit from social innovation, others may lose. Reasons for this can be the exclusion of some groups from the process, hijacking by extreme groups, the balance between financial and social objectives of social innovations and the risk and potential failure of social innovations. Moreover, to achieve real systemic change, dominant cognitive frames have to be overcome. This changing of cognitive frames as well as the challenging of normative roles and responsibilities may encounter resistance (Nicholls et al., 2015). This holds also true for the (crowdsourced) translations on Zooniverse that challenge the existing roles of professional translators and the decision-making responsibilities of researchers and platform providers. Translation changes social relations since it extends linguistic diversity, multilingualism and access and contributions to academic research. Volunteers wishing to promote or contribute to a project in their language now request (and produce) translations. From the perspective of the process dimension, this has an influence on governance and increases the level of participation. Moreover, it introduces some diversity to a platform that was initially created from an Anglocentric point of view and takes account of the fact that not every citizen scientist will be able to cope with English.

From a content perspective, translation fulfills a (social) need illustrated by the mainly non-solicited crowdsourced translations on Zooniverse, the translation requests by users and the use of machine translation for project pages by users. Although translation is accompanied by cultural differences, including terminological gaps, differences in seeing the world and in communicating with each other, which may be problematic in terms of unintended outcomes and misunderstandings, it can change social relations and increase empowerment. Translation is thus giving access to information, knowledge and resources. Translation increases capabilities since volunteers translate the content on their own. They get some control over the citizen science project as well as, the availability of information and resources in their language(s).

Especially technological progress and shifts toward the democratization of science can instigate (radical) change, also with regard to democratic knowledge creation and knowledge transfer. Therefore, citizen science plays a crucial role in knowledge translation (Heinisch, 2021). Participants in citizen science projects contribute actively to scholarly research and also dissemination, whereas translation is an important means of knowledge transfer. Thus, it can also serve as an instigator of social change and social innovation and can help deal with (epistemological) asymmetries (to a certain extent) by challenging existing paradigms and practices. To be successful, the citizen science community may need good practice guidance and policies on fostering linguistic diversity and translation (Desjardins, 2021).

Both crowdsourced translation and citizen science benefit from technological advances and the Internet as well as other developments, such as user-centered design, collaborative platforms, networks and user-generated content (shifting the focus away from mere passive users to active content producers) (O'Hagan, 2016).

Together these results provide important insights into the translation aspect of citizen science projects listed on Zooniverse. They demonstrate that especially the adaptation of material to a certain locale may indicate sensitivity to cultural differences and may be a driver of (social) innovation in and through citizen science. Although translation with regard to citizen science activities can result in the satisfaction of a social need and new social practices in the target locale that may increase the people's capacity to act, it may also result in the perception that local knowledge and local traditions are disregarded. Therefore, the results further support the idea of translation being an act of negotiating linguistic and cultural difference. Interestingly, in citizen science, terminology needs to be translated not only into another language but also translated (in the figurative sense) to a non-specialist audience. While this study did not further investigate on the importance of translation in citizen science, it did partially substantiate an unequal distribution of symbolic capital among languages. This can be derived from the languages in which the case study projects were translated. This further supports the idea of symbolically dominating languages when translating material for citizen science projects. This asymmetry can allude to the fact that the actors involved in citizen science may not be equal which is an obstacle to social innovation in and through citizen science. Nevertheless, the results also demonstrate that translation in citizen science may lead to a change of practices, including new ways how academics interact with the participants in citizen science projects. These are ingredients for social innovations.

Terminology is at the core of academic disciplines. It aims at unambiguous communication among domain-specific experts. Due to its specialized nature, though, the use of terminology also means to exclude members of the public from academic discourse. This becomes especially apparent in citizen science. Here, scholars and members of the public are the main actors that work toward a common goal specified by the relevant citizen science project. To achieve efficient communication, both actors have to make concessions to each other from a terminological point of view. The "translation" of concepts from one culture to another may result in changed social practices that are the drivers of social innovation.

Limitations

A limitation of this study is the concentration on the Zooniverse platform since it is primarily aimed at an international (English-speaking) audience. Moreover, the majority of the projects on Zooniverse have a focus on data analysis (and not on data collection). As mentioned in the discussion about agents and structures of translation in citizen science, the citizen science projects on Zooniverse may compete for the same participants, especially if they address the same topic and offer similar tasks. Since many Zooniverse projects ask volunteers to analyze data, persons interested in collecting data, e.g., being in nature and collecting samples or recording observations, etc. may not be attracted by the platform itself, since the tasks of Zooniverse projects can be basically completed from home by using only a computer.

The major limitation of this study is the focus on case studies on only one citizen science project platform. Therefore, further work in the form of in-depth studies of citizen science projects are needed to fully understand the implications of translation (and terminology) in citizen science and its effects on social innovation. Moreover, the interrelations between crowdsourced translation, multilingual project communication and citizen science beyond citizen science project platforms, including project websites and social media, would necessitate further analysis to take account of the multiple forms of translation in citizen science in the digital realm. Nevertheless, this work has been one of the first attempts to examine the relation between translation, citizen science and social innovation.

To develop a full picture of the role of translation, additional studies will be needed that further explore social innovation as a process. For the evaluation of social innovation as a process, developmental evaluation (Patton, 2016) may help to take account of the constant negotiation of a problem and its solution and the iterative emergence of a solution. Moreover, developmental evaluation is sensitive to the context and adaptation, i.e., the impact of innovations should be measured in their context (Antadze and Westley, 2012). Moreover, the situatedness of translation needs further investigation, especially the cultural and sub-cultural norms in different regions (Grimm et al., 2013), such as the consideration of different locales and also the cultural differences within locales.

Some citizen science projects on Zooniverse also have a project website outside the Zooniverse domain and among them are several projects that offer information on their website in other languages, i.e., languages that are not used on their Zooniverse project pages. Further research may investigate the reasons for not integrating these translations into the Zooniverse platform.

CONCLUSION

To reach participants, citizen science projects need to speak their participants' language. Especially for citizen science projects that have a global reach, translation is crucial to overcome language and cultural barriers to reach members of the public. Translation, understood as the transfer of meaning (of a text) from one language into another language, is essential for the transmission of information, knowledge and (social) innovations characterized by social change.

Although the translation of citizen science project websites and related materials and tools may contribute to social innovation, translation may not be primarily aimed at achieving social change but rather at reaching a broader audience. However, also the process (of translation) can lead to change, for example to new social relations and empowerment in and through citizen science. Languages offer different perspectives on the world. Seeing the world through a different lens (also through translation) is an important driver of social innovation. Translation may also result in an increased awareness for and appreciation of linguistic diversity in citizen science, the reduction of (cultural) biases and the consideration of translation by design.

Social innovation is characterized by the interrelatedness of social and institutional structure and agency. Translation can permeate all these agents and structures and support their role in the process of social change as part of social innovation. Thus, translation can contribute to the change of social practices and to the spread of social innovation, such as citizen science (as a manifestation of social innovation).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Citizen Science, Education, and Learning: Challenges and Opportunities

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Citizen science is a growing field of research and practice, generating new knowledge and understanding through the collaboration of citizens in scientific research. As the field expands, it is becoming increasingly important to consider its potential to foster education and learning opportunities. Although progress has been made to support learning in citizen science projects, as well as to facilitate citizen science in formal and informal learning environments, challenges still arise. This paper identifies a number of dilemmas facing the field—from competing scientific goals and learning outcomes, differing underlying ontologies and epistemologies, diverging communication strategies, to clashing values around advocacy and activism. Although such challenges can become barriers to the successful integration of citizen science into mainstream education systems, they also serve as signposts for possible synergies and opportunities. One of the key emerging recommendations is to align educational learning outcomes with citizen science project goals at the planning stage of the project using co-creation approaches to ensure issues of accessibility and inclusivity are paramount throughout the design and implementation of every project. Only then can citizen science realise its true potential to empower citizens to take ownership of their own science education and learning.

Keywords: learning environments, teachers, ontology and epistemology, activism, science communication, public engagement

INTRODUCTION

Citizen science has long been considered to hold vast potential in the field of science education and learning (Bonney et al., 2009a). It is also a rapidly growing field of research in its own right, with increasing prominence in areas such as astronomy, ecology, meteorology, and medicine (Lewandowski et al., 2017). As the term "citizen science" applies to science that involves people who are not professional scientists, it occupies a unique position in the scientific community. As well as being its own distinct field of enquiry (Jordan et al., 2015), it can also reach beyond individual scientific disciplines to attract wider public participation in scientific research, leading to the overall advancement of scientific knowledge (Bonney et al., 2009b). Citizen science has ample capacity for transdisciplinarity and for integrating natural, physical, and health sciences with the humanities and social sciences (Pykett et al., 2020; Tauginiene et al., 2020). It is an excellent method of harnessing non-traditional data sources to tackle societal challenges and contribute to certain Sustainable Development Goals of the United Nations (Fritz et al., 2019; Fraisl et al., 2020).

A number of associations have been established world-wide, with the aim of bringing together people who are involved in citizen science. The most distinguished of these are the Citizen Science Association (ostensibly a US-based association, but offering global membership), the European Citizen Science Association, and the Australian Citizen Science Association. Each of these relatively new associations have highlighted education and learning as critical issues for citizen science as an emerging professional field (Storksdieck et al., 2016; Roche and Davis, 2017a). Citizen science has the capacity to "develop connections between students' everyday lives and science so that they will have tangible reasons for continuing with the lifelong learning of science" (Jenkins, 2011, p. 501). It can function as a means of engaging the public with science on the scale of individual experiments, creating a unique position of combining participation, monitoring, and social change (Doyle et al., 2019; Dawson et al., 2020). Citizen science also offers a route by which the tenets of responsible research and innovation (Owen et al., 2012) may be fulfilled, particularly by facilitating lesser-heard communities in having their voices heard in relation to scientific policy-making and governance. This is now of more importance than ever, as researchers and academic experts find society's trust in their authority diminished (Roche and Davis, 2017b), while the COVID-19 pandemic has demonstrated the acute need for public trust to be strengthened (Henderson et al., 2020). Indeed, citizen science might offer a more pressing model for science in a post-pandemic world (Provenzi and Barello, 2020). Despite its growing importance, citizen science is rarely considered in terms of science education research (Kelemen-Finan et al., 2018). For the purposes of this paper, the term "science" is taken to encompass systematic and evidence-based investigations in the pursuit of new knowledge, while the term "education" is considered to be the acquisition of knowledge through learning. Learning can be self-directed, but often relies on the guidance of a teacher. The learning can take place in either formal or informal environments and the methods of teaching, or pedagogy, can be as varied as the settings themselves. While these definitions are not all-inclusive, they provide a starting point where science, education, and learning can be considered in relation to the emerging challenges and opportunities stemming from citizen science.

Supporting Citizen Science in Education and Learning

In order to ensure that citizen science lives up to its vast potential to extend beyond individual projects and disciplines, opportunities for strengthening the relationship between citizen science and education must be identified so that appropriate support can be offered and integration achieved. Many questions have been raised regarding the role of citizen science within science education (Bonney et al., 2016); even the term "citizen science," and the individual component words of that term can have different meanings subject to context (Eitzel et al., 2017). A report prepared by the US National Academies of Sciences, Engineering, and Medicine set out to tackle these issues—not simply by discussing the "potential of citizen science to support science learning" but by endeavouring to "identify promising practices and programs that exemplify the promising practices, and lay out a research agenda that can fill gaps in the current understanding of how citizen science can support science learning and enhance science education" (National Academies of Sciences, 2018, p. 2).

In Europe, efforts are also underway to identify the challenges and opportunities that may arise when citizen science and education are brought together through project collaboration, networks, research, and practice. Alongside the European Commission's "Science with and for Society" work programme (European Commission, 2017), and the European Citizen Science Association, a COST Action (CA15212) was also established in order "to promote creativity, scientific literacy, and innovation throughout Europe" through citizen science (COST, 2016). This COST Action included a working group entitled "Develop synergies with education" and, through a dedicated workshop, brought together researchers and practitioners with a range of different backgrounds and contexts for interpreting citizen science in relation to education and learning. The subsequent discussions that emerged from the working group led to this paper, which provides an international perspective on some of the main challenges and opportunities facing citizen science in education. While the diversity of the working group ensured that a broad selection of perspectives were considered, it was by no means exhaustive. There are undoubtedly other arising challenges and opportunities that have not yet been considered, and it is hoped that this paper will serve as a starting point for developing a comprehensive research agenda for supporting citizen science in education and learning.

CHALLENGES FOR CITIZEN SCIENCE, EDUCATION, AND LEARNING

Every person who participates in citizen science is also involved in a learning process (Bela et al., 2016), not just the acquisition of the skills necessary for participation in citizen science, but also a deeper understanding of scientific concepts and processes—historically referred to as "scientific literacy" (Miller, 1983). The development of scientific literacy in tandem with the contribution to genuine scientific outcomes has been a longstanding goal of the field (Brossard et al., 2005; Jordan et al., 2011; Saunders et al., 2018). Logistical tensions tend to arise between citizen science and education due to unavoidable constraints concerning time, space, staff, and other key resources. While training could help address a number of these issues, the associated costs often present a barrier, especially in fields where participant goodwill and volunteer work are crucial (Lorke et al., 2019). Many citizen science projects have little flexibility in terms of timing and the allocation of resources, and navigating these issues will invariably remain challenging for many citizen science coordinators and programme managers.

Beyond logistics, the goal of citizen science—to bring about scientific progress—and the goal of education—to support learning—may not necessarily always align. Citizen science can be integrated into education in both formal and informal learning environments. Formal learning generally occurs in school, college, or university environments with clear learning objectives, whereas informal education can take place outside of the classroom or after school, often in public engagement spaces like museums, zoos, or aquariums (Eshach, 2007; National Research Council, 2009). Each environment raises unique challenges for practitioners. Challenges may also arise as a result of the different needs of the scientists, students, teachers, educators, researchers, and other actors involved; the issue of how information is communicated and shared; as well as from potential conflict between the capacity of citizen science for activism and the desire or obligation to reach specific learning objectives.

Citizen Science and Education in Formal Learning Environments

Specific learning objectives, background information, and lesson plans are generally utilised by educators to integrate citizen science projects into curricula in formal learning environments, particularly when teaching children and adolescents at primary and post-primary level (Bonney et al., 2009b, 2014). Consequently, project engagement becomes contingent on the educators themselves; as the students or learners may have been effectively volunteered to participate, rather than electing to do so, motivation and engagement may be lacking compared to other groups of citizen science participants. Therefore teachers, as the citizen science intermediaries in formal learning environments (Weinstein, 2012), play a crucial role in successfully integrating such projects into their classrooms and schools. That some teachers may lack confidence in their own general level of scientific content knowledge and scientific literacy can considerably impede this process—for example, issues of content knowledge could arise on projects that require teachers to explore outdoor environments where they cannot fulfil the perceived demand to be an expert (Kelemen-Finan and Dedova, 2014; Jenkins et al., 2015). The participation of schools can also be constrained by school curricula, timetables, or logistical issues. For those teachers and schools that are interested in engaging in citizen science projects, it may be difficult to navigate the rapidly growing number of initiatives available to them.

Additional challenges stem from the type of classroom involvement that can be facilitated. Projects such as the Monarch Larva Monitoring Project (Kountoupes and Oberhauser, 2008) or Classroom FeederWatch (Bonney and Dhondt, 1997) are considered examples of best practice from the last two decades, where materials are provided for local school involvement, while generating valuable data for the project at large. Both of these projects offer web tools for downloading data, as well as instructions for data analysis to empower participants to perform their own analysis. The construction of materials, the maintenance of an interactive website, smartphone apps, and continuous email contact requires considerable resources, especially in terms of staff with relevant experience in science and education. More recent projects like the School of Ants (Lucky et al., 2014), LandSense (Olteanu-Raimond et al., 2018), and eMammal (Schuttler et al., 2019) have mirrored the success of these large-scale schools projects, while national schools-based citizen science projects in the future are likely to tackle aspects of post-pandemic life (Eichler et al., 2020; Ugolini et al., 2020). Smaller contributory projects sometimes lack such infrastructure and resources and, consequently, participants are often only involved in data collection without gaining experience of the complete inquiry process (Jenkins et al., 2015). Zoellick et al. (2012) argue that a third party, for example, a university, is a necessary intermediary between scientists and educators in order to ensure that specific research and educational outcomes are ultimately achieved. Their proposed model for school-based research projects describes scientists' and educators' inputs, their interactions during the design and implementation phase, and separate outputs and outcomes for students and scientists. While this model addresses the tension between collaborating scientists, schools, teachers, and students, it could be further improved with the added consideration of student input alongside outcomes for the educators (Jenkins, 2006). Co-constructed citizen science projects, where students are actively involved in the scientific process are labour and resource intensive for scientists, students, and teachers, but are more likely to achieve the scientific and educational goals of the project (Gray et al., 2012).

Citizen Science and Education in Informal Learning Environments

Informal education generally refers to the learning that takes places outside of classrooms and lecture theatres. Informal environments may sometimes be further subdivided into non-formal and semiformal categories (Werquin, 2007), but for the purpose of this paper, all learning environments outside of those involving schools, higher education, or universities, can be considered informal. Informal learning environments, such as science centres and museums, are critical to science education. Citizen science projects find a natural home in these domains due to a shared strong commitment to public engagement (Dickinson et al., 2012; Ballard et al., 2017).

The impact that citizen science projects can have on education in these environments is affected by the same challenge that faces informal learning environments in general—finding the best way to support learners and facilitators (Stewart and Jordan, 2017). Tension may arise between designing projects that are "fun" for casual participants and ensuring that data generated is of sufficient quality. The use of "fun" activities can increase participation, create interest in a given research topic, and nurture a love of science—particularly in projects involving young people (Kountoupes and Oberhauser, 2008). However, there may be a trade-off regarding the time and resources necessary to make these activities engaging, and the efforts to serve the scientific and educational goals of the project. A report by the US Committee on Learning Science in Informal Environments in 2009 found that although tensions often arise between the "reasonable goals for learning science in informal environments" and the education "agenda," it was deemed 'unproductive to blindly adopt either purely academic goals or purely subjective learning goals' in informal learning settings (Bell et al., 2009, p. 3).

The learning that takes place in informal environments through citizen science projects can be difficult to capture. Initial efforts have been undertaken to find ways to evaluate the intended learning outcomes for the participants in these projects (Phillips et al., 2014, 2018), but Edwards (2014) has highlighted that the specific impact that citizen science can have on the lifelong learning of people outside the classroom has not yet been comprehensively explored. Likewise, while understanding social and cultural capital is critical to interpreting how people engage with informal science education institutions (Dawson, 2014), there has not yet been enough consideration given to how this capital affects participation in citizen science projects and the resulting issues of equity that may emerge (Birmingham, 2016). Citizen science has the same issues of inequity that are endemic throughout society, with innate barriers to participation for minorities and underserved communities (Soleri et al., 2016; Fiske et al., 2019). Science capital—a concept that explores how a person's environment and social class can affect their involvement in science—could allow "inequalities in science participation" to be discovered more readily, which in turn could be used to promote "social justice within science education" (Archer et al., 2015, p. 943). If citizen science is to fulfil its potential in improving equity of access to, and participation in, both science and science education in informal learning environments, then "the extent to which citizen science can build science capital and enable wider engagement with science-related issues [...] deserves further experimentation and investigation" (Edwards et al., 2018, p. 390).

Citizen Science, Education, and Activism

Arnstein (1969) pioneered the concept of citizen participation with her "Ladder of Citizen Participation," which described the eight levels of citizen power, from non-participatory "manipulation" to "citizen control." The role citizen science may play in activism and in advocacy—citizens intervening on behalf of, or representing, a socio-political goal (Letiecq and Anderson, 2017; Reis, 2020)—is a key consideration in its interactions with education and learning. From the perspective of civic society, citizen science should encourage individuals to take an active role in their communities—operationalizing active citizenship (Burls and Recknagel, 2013). This role of active citizenship aligns with Arnstein's rising level of citizen participation and is especially pertinent in citizen science projects that focus on environmental activism and climate change—empowering people to take responsibility for the future of their environments (Baptista et al., 2018; Kythreotis et al., 2019; Dawson et al., 2020). The concept of active citizenship is closely aligned to the UNESCO Incheon Declaration and Framework for Action (UNESCO, 2015) which seeks to ensure inclusive, equitable, and quality education on a global scale. It encompasses three distinct dimensions: a citizen's legal citizenship, socio-economic background, and socio-cultural background (Kalekin-Fishman et al., 2007). Legal citizenship enables an individual to channel their political agency, although, as highlighted by Eitzel et al. (2017), the definition of citizenship is complex and can be problematic in some contexts. Socio-economic power can create demand for education, transforming learning into a desirable consumer commodity and potentially creating resources that can supplement underfunded or overlooked government services. The socio-cultural dimension of active citizenship focuses on ethics, and seeks to foster cohesion, inclusion, and tolerance in the personal and public spheres. Citizen science practice could be exercised as one means of educating active citizens; by empowering communities to advocate for their local environment through research, or by enabling citizens to gather evidence on, and articulate, pressing issues. The results of active citizenship, often shared with the wider public through social media, can even hasten the actions of decision-makers (Eitzel et al., 2017).

However, despite the benefits of potentially bolstering science education through active citizenship, tension may arise between the traditional role of the learner in some learning environments, acquiring pre-determined knowledge and values, and the process of learning continuously through active citizenship, which may result in social transformation. Educators may feel uncomfortable in sharing decision-making power with other participants in citizen-led activities and may feel uncertainty as to the value of that learning process (Mueller and Tippins, 2015). In citizen science activities, practitioners, and participants may not be able to retain their usual roles in some learning environments (Fazio and Karrow, 2015) and significant changes may need to be made in order to enable and facilitate social activism.

Theoretical Perspectives on Citizen Science and Educational Practice

Ontologies and epistemologies are theories surrounding the nature of being and knowing, or generating knowledge, and provide the assumptions which naturally underlie both educational practice and citizen science practice. Ontology and epistemology are often linked, because how the world is understood, and the phenomena that are available for study within it, are very much dependent on how people think they can come to know, and what they consider "valid" knowledge. Therefore, onto-epistemological differences, namely, tensions that arise from the disparate ways each person interprets the world, including the understanding of what phenomena can be studied, how it can be studied, and the conclusions that can subsequently be drawn, mean that the differences inherent between various citizen science fields and educational environments will result in disparate learning outcomes. As noted by Shirk et al. (2012), tension may be generated due to the often dissimilar interests of scientific and public stakeholder groups in the wider field of public participation in scientific research (PPSR), in which citizen science is intrinsic. Competing onto-epistemologies are likely contributory factors to the difficulties inherent in engaging various publics in scientific research, and the alignment of these competing constituents could facilitate greater synergy between citizen science and education.

Building on Arnstein's concept, Haklay (2013) designed an adapted model for citizen science in which the fourth and final level of citizen participation enables all stakeholders—scientists, educators, facilitators, the public, education partner organisations, and policy makers—to collaborate. At this level, citizen science would emerge as a truly transformative practice that has the power to change and influence the world. In his typology, Haklay's (2013) suggests that increasing the involvement and engagement of the public in citizen science will result in the empowerment of learners while significantly democratising citizen science input. As members of the public are empowered to engage more deeply with, and learn more about the scientific projects they are involved in, they are likely to move up the structure—from merely acting as sensors for science projects that are conducted elsewhere, to collaboratively shaping scientific endeavours from their inception, and participating in their analysis throughout.

Competing tensions in citizen science can also be considered through three stances in education suggested by Stetsenko's (2008) acquisition, participation, and transformation—which are evident at each level of Haklay's typology. In the first stance, "acquisition," stakeholders see citizen science processes as being concerned with generating pre-existing, fixed, factual knowledge that is gained by individuals primarily through passive input. The second stance, "participation," positions science and education practices as potentially being affected by other factors—such as location or culture—and necessitates an initiation process in order for participants to gain full access to the community. This stance places citizen scientists into a more participatory role, and educators and scientists are aware that citizen science often generates findings that are culturally located, generated, shared, mutable, and communicated over time. This stance may bring about tension from stakeholders who don't wholly subscribe to the idea that findings are culturally embedded; however, "participation" provides access for novices, e.g., pupils, into the community of science practitioners.

Applying Stetsenko's third stance, citizen science can become "transformative" when embedded in educational programming. This transformation could lead to change at individual, community-wide, and global levels if citizen science expands in scale and scope. The intrinsic risk of the transformative approach is that it can replace a system of knowledge with one that still does not appropriately recognise marginalised forms of knowledge (Leibowitz, 2017). An example of a transformative project could be "WeatherBlur" a co-created citizen science project bringing together, fishermen, students, teachers, and research scientists from island and coastal communities on the east coast of the US "to share, analyse, and interpret data about the local impact of climate change" (Kermish-Allen et al., 2019, p. 627). "Knowing" and acquiring knowledge are presented by Stetsenko as active and collective activities; thus citizen science would evolve into a collaborative, co-creative approach. This transformative stance embodies the fourth level of Haklay's typology; presenting an ideal common ground for both education and citizen science, resolving potential onto-epistemological tensions, and generating synergy.

Dissemination, Dialogue, and Participatory Communication

Citizen science projects often aim not only to advance scientific knowledge, but to share it too. The manner in which communication takes place in these projects, and the effect it has on learning, must tread the line between outreach and engagement, and warrants a communication plan that not only connects with the right audiences but retains their interest over time (Veeckman et al., 2019). Projects tend to adopt either a two-way approach that emphasises participatory dialogue (McCallie et al., 2009; Haywood and Besley, 2013), or a one-way approach that focuses on outreach and dissemination.

Two-way communication between citizens and scientists within projects leads to the sharing of ideas, information, and knowledge, while one-way dissemination to a wider audience can involve the communication of results, funding-specific public relations obligations, or participant recruitment (Tulloch et al., 2013; Groulx et al., 2017). While the two-way participatory approach is more time consuming, and can put additional pressure on project resources, it is more likely to foster collaborative work, relationship building, and learning (Mercer and Littleton, 2007). The tension between outreach and engagement is mirrored in the field of science communication with its models of deficit and dialogue (Trench, 2008; Lewenstein, 2015).

Whereas participatory engagement is a powerful way to support learning (Gleason and Von Gillern, 2018), one-way dissemination also has a valuable role in citizen science. Communicating the mission and vision of a project outside of its immediate community can be one of the most important goals for project leaders (Kerzner, 2013). The way in which these values are communicated can vary, depending on the scientists, citizens, and policymakers involved. In particular, there is often a perceived disconnect between policymakers and other key stakeholders, such as citizens and scientists (Socientize Consortium, 2013). Using a Public Relations (PR) approach is a commonly employed method of bridging this gap (Scott, 2013), and involves implementing a strategic communications plan that can include public lectures, workshops, festivals, exhibits, tours, and open laboratories. To supplement these activities, a strategic PR plan for citizen science projects is often used to directly engage policymakers with demonstrations of the usefulness of the project and the need for new knowledge generation (Socientize Consortium, 2014). Although a common concern when employing a communication approach that focuses on PR is the potential tendency to overlook negative results and issues of uncertainty, which are part of the scientific process, if effective communication is adhered to between stakeholders, it can lead to citizen science projects enhancing public debate and citizen participation in decision-making processes, especially regarding societal challenges (Newman et al., 2012).

In as much as onto-epistemological tensions may arise between citizen science and education, one-way dissemination may generate significant tension in a learning environment when science is positioned as the sole truth, and the scientific method the only way to produce reliable knowledge. A two-way participatory approach, by contrast, not only bridges the gap between science education and science communication but poses science as one of many types of knowledge, and the scientific method as one of a multitude of ways to describe the world (Baram-Tsabari and Osborne, 2015). This interplay between science and society is ever more critical in the era of fake news and misinformation (Scheufele and Krause, 2019). One of the most effective solutions to such tensions is to involve scientists in all aspects of the communication process in citizen science projects (Riesch and Potter, 2014). This has a positive effect on participant recruitment, retention, instruction, knowledge sharing, awareness raising, and increases the credibility and authority of the work taking place. However, some scientists may be hesitant to engage in efforts to communicate if they feel that they are not specifically trained to do so (Golumbic et al., 2017). Communication activities, such as public talks, interviews, or popular science articles can be time consuming, and some scientists may find participation uncomfortable (Van Vliet et al., 2014). An increasing number of research funding initiatives at both national and European levels require the inclusion of public engagement and communication strategies, thus increasing the pressure on scientists involved in citizen science projects to directly engage with public audiences. This may be particularly challenging for scientists if these activities are not supported by their institutions, or if their career progression is primarily evaluated on the quality of their publications in scientific journals (Kreiman and Maunsell, 2011). While not without its critics (Khazragui and Hudson, 2015; Watermeyer, 2016), the Research Excellence Framework in the UK is a notable example of a research evaluation process that gives consideration to the societal impact of research.

OPPORTUNITIES FOR CITIZEN SCIENCE, EDUCATION, AND LEARNING

Thoroughly exploring the obstacles that prevent the successful integration of citizen science practice into mainstream education systems is key to overcoming them. Recommendations based on the challenges that have been highlighted in this paper could help citizen science to fulfil its potential as a truly transformative social innovation for education and learning. This could, in turn, encourage citizen science practitioners and educators to take an adaptive and flexible position in the face of new and emerging societal challenges and a fluctuating political and economic landscape that continuously strains the relationship between science and society.

Recommendations for Finding Synergy

There has already been a great deal of work conducted with a view to establishing best practice principles for citizen science notably, the European Citizen Science Association's "Ten Principles of Citizen Science" [European Citizen Science Association, 2015; and the subsequent characteristics of citizen science (European Citizen Science Association, 2020) which expand on the principles]. Assuming adherence to these principles, the following recommendations may create meaningful opportunities for citizen science in education and learning.

Professional development training workshops (Jeanpierre et al., 2005) facilitating citizen science in classrooms can be effective in overcoming some of the barriers that schools, teachers, and students may encounter while participating in citizen science projects (Eberbach and Crowley, 2009; Scheuch et al., 2018). Crall et al. (2013) demonstrated that such workshops could improve scientific literacy for workshop participants, assessed with context-specific measures. However, unique challenges are still likely to arise. Jordan et al. (2011) could not detect any increase in scientific literacy, and the potential failure of these training sessions was attributed to a lack of time for active learning, which must provide a provision for reflection, and allow participants to make mistakes (Gray et al., 2012; Jordan et al., 2015). To further embed citizen science in informal learning spaces, gamification is an effective tool in engaging participants, and in-game rewards can be carefully planned in order to reward focus on good quality data (Tippins and Jensen, 2012; Bowser et al., 2013; Morschheuser et al., 2019; Piper, 2020).

Ensuring alignment between the onto-epistemological positions of the citizen science, education, and learning aspects of any project is a worthwhile endeavour. It is clear that the achievement of the educational goals of citizen science projects are contingent on those goals being taken into consideration at the design stage (Bonney et al., 2014). Following frameworks for measuring individual learning outcomes from participation in citizen science—such as Phillips et al. (2018)—would facilitate the alignment of learning outcomes and the underlying onto-epistemological stances. Additionally, building a co-creation component into citizen science projects from the outset would significantly increase the likelihood that both the educational and scientific goals of the project will be met (Gray et al., 2012). Such co-creation approaches should be considered obligatory, where possible, for every new project.

Challenges surrounding communication, dissemination, and dialogue may be addressed by increasing science communication training opportunities for scientists involved in citizen science, as well as for scientists in general. Collaboration between scientists and citizens with public relations and communication professionals could lead to more open strategies for communicating with different audiences and could generate clear alignment between both the dissemination and participatory modes of communication. Crucially, to ensure that scientists contribute not only to the scientific goals of citizen science projects, but also to the communication and educational aspects, public engagement should be recognised as scholarly work. This would be made possible through research institutions redefining public engagement as a metric to be evaluated in academic career progression, in a manner akin to research output (Smith et al., 2014).

The greater recognition of citizen science and activism in recent years may, in part, be due to a growing focus on equality, open access, and public participation caused by the current global political climate (Roche and Davis, 2017b; Hutter and Kriesi, 2019). Once public engagement is fully integrated into the missions of both research performing organisations and research funding organisations, social activism must be given due consideration as an inevitable counterpart to citizen science. As recommended by the National Academies of Sciences (2018), issues of equity and power should be given particular consideration at all stages of citizen science project design and implementation, in all settings. Citizen science is not merely a method of involving the public in scientific research but is also a way of empowering citizens to take ownership of their own science education and learning.

The Future of Citizen Science in Education and Learning

Transformative approaches to education are becoming more widely accepted; within education, and in higher education specifically, there is significant interest in developing co-researcher partnerships (Healey et al., 2016). Such partnerships can lead to the co-design of curricula (Bovill, 2014) and the co-production of knowledge (McCulloch, 2009). A contributory approach necessitates a whole new learning paradigm requiring novel educational methods. The outdated metaphor of 'students as consumers' (Dearing, 1997; Palfreyman and Warner, 1998), which has a negative impact on student engagement and performance (Bunce et al., 2017), could be replaced by a citizen science partnership that supports educators and students, where knowledge is exchanged in both directions, and the students are active partners in their learning (Freeman et al., 2014) and in participating in authentic scientific research.

Citizen science practitioners and programmes seeking links with schools may find that tapping into more transformative models of learner engagement is a starting point for enhanced participation. The adoption of a transformative onto-epistemological stance opens up much greater potential for synergy between citizen science and education. The outcomes of transformative citizen science will result in changes to what is known, how it is known, and to the individual, socio-cultural, and wider world. Mueller and Tippins (2012) rhetorically ask why citizen science programming in education generally aims to advance science literacy, when learners' motivations are predominantly to care for what is often a local environment. Within this transformational framing, potential exists for attending to learning and practicing science in ways that are more in tune with learners' motivations, with local places, and in ways that are socio-culturally distributed among all participants, including scientists, teachers, students, community members, policymakers, and any other stakeholders (Mannion et al., 2013; Haywood et al., 2016). Taking a transformative stance on citizen science in education could be key to engendering a more vital role for science in the public sphere, generating responses to current and future eco-social problems (Dillon et al., 2016), and helping to achieve the UN Sustainable Development Goals (Fritz et al., 2019; Fraisl et al., 2020).

The future of how citizen science will be integrated into education and learning will continue to be influenced by globally-accessible digital platforms. The newest of these, EU-Citizen.Science, is an online platform for citizen science in Europe that is being established with the support of a Horizon 2020 grant from the European Commission. This platform will not only make citizen science projects and data more readily accessible, but it will also act as a mutual learning space for sharing useful tools, guidelines, training, and best practice examples in several languages to help citizens, scientists, teachers, students, schools, and other stakeholders to determine how they can engage with local and international citizen science projects. Global initiatives such as these will be key to realising the education and learning potential of citizen science as a far-reaching social innovation.

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JR and SW were the lead authors and oversaw the completion of the writing. JR, LB, CG, YG, LK, NK, ML, JL, GM, LM, AM, KP, AR, PT, and SW contributed writing to individual subsections of the manuscript. All authors have read and agreed to the published version of the manuscript and were involved in the conceptual design of the manuscript.

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Citizen Science in Ireland

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Ireland has a rich history of public engagement with science and the growing number of national citizen science initiatives is in keeping with developments seen in other European countries. This paper explores several aspects of citizen science in Ireland, in order to assess its development and to better understand potential opportunities for the field. An introduction to the roots of citizen science in Ireland's past, from the first methodical observations of natural phenomena carried out at monastic settlements up to present day projects monitoring environmental change and biodiversity, is presented along with an overview of the current national citizen science projects running in the country. This cataloging of contemporary citizen science will be compared to the awareness of citizen science in the Irish education system at primary, post-primary, and university level. These measures of progress will be considered in the changing context of international citizen science funding and available support, such as the European Citizen Science Association and the EU-Citizen.Science platform. Citizen science in Ireland is at a critical point. If citizen science is embraced as a truly social and participatory innovation, Ireland has the chance to not only dramatically improve its citizen science output, but to also become a model of best practice for countries at similar stages of citizen science development.

Keywords: citizen science, Ireland, education, citizen scientist, public engagement, science communication, science and society, informal learning

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PUBLIC ENGAGEMENT WITH SCIENCE IN IRELAND

Citizen science refers to scientific research that involves people who do not identify as professional scientists. It can also refer to a theoretical or practical approach to research as well as being a field of research in its own right (Roche et al., 2020a). While the theoretical context of the individual terms "citizen" and "science" can vary greatly depending on a range of factors and circumstances (Eitzel et al., 2017), citizen science can provide a general indicator of a country's relationship between science and society. Public perceptions of science in Ireland are worth exploring at several key historical junctures. Taking stock of this history of engaging with science provides context for the current state of citizen science in the country and indicates potential future directions for the field.

Monastic Observers and Early Natural Philosophers

Ireland is home to one of the earliest and most significant historical sites for scientific observations. The Newgrange megalithic passage tomb near the River Boyne in Meath predates both Stonehenge and the Egyptian Pyramids and is considered to be "the oldest megalithic structure known for certain to have an astronomical function" (Ray, 1989, p. 344). Long before the term "science" existed, natural philosophers in Ireland were making systematic observations of the natural world around them. One of the first records of scientific writing in Ireland is from an unknown philosopher nicknamed "Augustinus Hibernicus", who carried out astute observations of the Irish environment in the seventh century while trying to reconcile those observations with biblical teachings (Moriarty, 1997).

The Irish annals—annual listings of events in Ireland recorded firstly by monastic communities and later by professional historians—are one of the most important sources for dating the role of science in early medieval Ireland (MacNiocaill, 1975; McCarthy, 2008). Although McCarthy and Breen (1997) highlight how the vast majority of the records provide a scattered and inconsistent overview of political and ecclesiastical events in Ireland, they also note that the annals contain observations of a range of phenomena such as "eclipses, comets, strange clouds, earthquakes, storms, famines, [and] plagues" (p. 118). The propensity for information to be written in the vernacular, and not just the more rarefied Latin that was the staple of monastic records across Europe at the time, made the work more accessible to local people (Bisagni and Warntjes, 2008). This meticulous cataloging of events in the natural world means that these monastic observers were some of the first citizen scientists—people systematically collecting data in order to better understand their environment (Silvertown, 2009).

From Medieval Ireland to the Golden Age of Irish Science

The history of natural philosophers in Ireland is not widely studied, in part due to the fact that there has traditionally been a dearth of professional practitioners focusing on the history of science (Outram, 1986). Although the first natural philosophers in Ireland were mostly confined to monasteries, by the 16th and 17th centuries Irish citizens could engage with science in places of public education, although these were still largely inaccessible to the vast majority of Irish people. The political and religious divisions in the country meant that the working class, largely Catholic, population of Ireland were less likely to have access to education and it was predominantly the upper classes, or "Protestant Ascendancy" (Hill, 1984), for whom engagement with science became more accessible.

The founding of the University of Dublin, Trinity College, in 1592 by Queen Elizabeth (McDowell and Webb, 2004) was significant, as medieval universities across Europe were the only places where meaningful science learning could take place at the time (Pedersen, 1997). The subsequently established Dublin Philosophical Society at Trinity College in 1683 became the first gathering of natural philosophers in Ireland to publicly share their learnings (Wilde and Lloyd, 1844). The society was modeled on the most famous at the time, the Royal Society in London (Hoppen, 1982), and this increased public engagement with science, at least in the upper classes, overlaps with the "golden age for Irish science"—a period spanning the 18th and 19th century when Ireland was home to renowned scientists in fields such as mathematics, geology, astronomy, "enjoying the highest of international scientific reputations" (Davies, 1985, p. 297).

Scientific Research and Education in Modern Ireland

Since the 19th century, political, religious, and economic factors have all played their part in shaping how Irish citizens engage with science. The Catholic Church in Ireland initially deemed engagement with science and science education as being a threat to the Catholic faith (O'Riordan, 1897; Finnegan and Wright, 2015) and it was not until the early 20th century that scientists in Ireland could more freely engage the public, as the clergy abandoned efforts to provide meaningful competition with scientists in their interpretation of the natural world (Turner, 1978). By that stage, the professionalization of science across Europe (Ellis, 2014) was amplified in Ireland by the Irish state's commitment to widespread access to education (Loxley et al., 2014) and later to scientific research funding (HEA, 2017). This signaled a move from an economy traditionally grounded in the manufacturing and agriculture industries, toward a more knowledge-based economy. Although Ireland's expenditure on scientific research remains below the average for European Union countries (OECD, 2004; Butler, 2015), modern Ireland has a strong education and research environment with clear capacity for supporting citizens engaging with science.

CITIZEN SCIENCE IN CONTEMPORARY IRELAND

Citizen science projects, by their nature, can be participant-led, informal, and community-based. All of these aspects are strengths of the field, but this also means that some projects are difficult to capture in a systematic cataloging of initiatives. The most comprehensive examination of citizen science in Ireland to date is the work of Donnelly et al. (2014), which investigated the monitoring of biodiversity in Ireland and found that in grassroots initiatives the quality and the reliability of the data collected were not always at a high enough standard to be of scientific value. Specifically, there was a scarcity of formal data validation checks embedded in citizen science projects in Ireland. As the use of technology in citizen science has evolved and with platforms for collaborating and sharing best practices (See 'International Opportunities' section below), the recommendation by Donnelly et al. (2014) to consider data validation, verification, and harmonization methods for international comparability as a way of ensuring the success of citizen science projects is more pertinent than ever.

National Citizen Science Projects

A number of organisations in Ireland have initiated national citizen science projects or have actively supported them. The main organisations supporting citizen science in Ireland are listed in **Table 1**.

In general, citizen science initiatives in Ireland are localized and only have the capacity to "become national endeavors" when they have the support of an established public or private organisation (Eitzel et al., 2017, p. 9).

The projects shown in **Table 2**—which provides an overview of citizen science projects in Ireland in 2020—were gathered by collating publicly available information from national organisations, public websites, and social media. The projects were cataloged according to Haklay's (2013) typology of participation. This typology has four levels of participation and engagement in citizen science, ranging from:

TABLE 1 | Organisations involved in citizen science in Ireland.

Organisation name	Organisation type	Involvement in citizen science
An Taisce	The National Trust for Ireland and the oldest environmental and non-governmental organisation in the country, founded in 1948	Leads the Irish arm of the "global learning and observations to benefit the environment" (GLOBE) citizen science programme
Environmental Protection Agency	Independent public body	Includes citizen science in its remit of environmental protection and policing, with a particular research focus on climate, water, and sustainability
Geological Survey Ireland	Part of the Government's Department of the Environment, Climate and Communications	Maintains the National Public Earth Science Knowledge Centre and provides open access data and maps of Ireland's subsurface
Heritage Council	Statutory public body	Maintains and protects Irish heritage and supports citizen science through increased community engagement and heritage awareness
Irish Wildlife Trust	Charity funded by the Government's Department of the Environment, Climate and Communications	Runs the conservation groups Bat Conservation Ireland, Groundwork, and Badgerwatch Ireland
Marine Institute	State agency tasked with marine research	Promotes citizen engagement to support the sustainable development of ocean, sea, coastal and inland water resources
National Biodiversity Data Centre	Established and funded by the Heritage Council as well as the Government's Department of Culture, Heritage and the Gaeltacht	Responsible for cataloguing Ireland's biological diversity and maintains more citizen science projects than any other Irish organisation
National Parks and Wildlife service	State body and part of the Heritage Division of the Government's Department of Housing, Local Government and Heritage	Encourages citizen science as means to help foster public awareness for nature conservation in Ireland
Teagasc	State-funded Agriculture and Food Development Authority for Ireland	Promotes citizen science for supporting research and innovation in the agri-food and bioeconomy sectors
Universities and research centres	Public and private higher education institutions	A number of Irish universities and research centres have developed and supported citizen science projects in Ireland

crowdsourcing, where the participants are tasked with simple data collection; distributed intelligence, where some analysis is carried out by participants and may necessitate basic training; participatory science, where participants have more input into the process, including defining the problem itself; and the top level, extreme citizen science, where the participants and scientists are on equal footing throughout an integrated collaborative process.

It is possible that some grassroots projects that do not have an online presence or are not connected to a formal research or education organisation may not have been captured in **Table 2**. The recommendations in the final section of this paper offer some suggestions as to how this limitation could be addressed in future research. The table shows only current projects based in Ireland, so international citizen science initiatives that are available in Ireland, such as the Zooniverse suite of projects, are not included. Similarly, completed projects or those that are currently on hiatus are not included.

The National Biodiversity Data Centre, established by the Heritage Council in 2007, is involved in a significant portion of the citizen science projects in Ireland and maintains a national portal to record sightings of specific species (https://records.biodiversityireland.ie/start-recording) as well as regularly publishing biodiversity reports on topics such as endangered species (Fitzpatrick, 2013) and invasive species (O'Flynn et al., 2014). Recent citizen science projects in Ireland have tackled topics such as water quality (Quinlivan et al., 2020), biosecurity awareness (Melly and Hanrahan, 2020), and light pollution (Coogan et al., 2020).

The information collated in **Table 2** demonstrates the overall state of national citizen science projects across the country and illustrates three key points:

- National citizen science projects in Ireland are predominantly focused on environmental conservation.
- A small number of organisations are responsible for the vast majority of the citizen science projects in Ireland.
- While there are some exceptions, the vast majority of citizen science projects in Ireland can be classified as being 'Level 1: Crowdsourcing' according to Haklay's typology of participation.

Awareness of Citizen Science in Irish Education

Integrating citizen science and education is key to unlocking the potential for citizen science to be a truly social innovation (Kloetzer et al., 2021). To provide further insight into the state of citizen science in Ireland as presented in **Tables 1** and **2**, a basic impression of the awareness levels of citizen science among educators in Ireland is provided in **Table 3**. In 2018 and early 2019 three separate groups of educators in Ireland were surveyed about their familiarity with the term "citizen science". These three groups were: primary school teachers (n = 50), post-primary science teachers (n = 114), and university-level scientists (professors and research fellows, n = 157). While stratified random sampling was used to contact both teacher groups, with surveys being sent to a cross-section of schools around the country, convenience sampling was used to reach the university educators. As such, the data presented in **Table 3** are neither exhaustive nor definitive, but merely provide an illustrative example of awareness levels in a critical area of citizen science research that deserves more attention in Ireland.

The survey participants in **Table 3** who answered that they had encountered the term "citizen science" were subsequently invited to define the term in their own words. Further insight into the awareness of citizen science among educators was provided by comparing these definitions from the participants with a benchmark definition, the Oxford English Dictionary's 2014 definition of citizen science: "Scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional

TABLE 2 | Citizen science projects in Ireland in 2020.

Project name	Host organisation	Study subject	Website link
All Ireland CoastWatch Survey	CoastWatch Europe	Coastal wildlife and fauna	http://coastwatch.org/europe/survey/#all-ireland-survey
All Ireland Ladybird Survey	Fota Wildlife Park and University College Cork	Ladybirds	http://www.biology.ie/home.php?m=ladybirds2
Backyard Biodiversity Species	National Biodiversity Data Centre	Garden wildlife species	https://www.biodiversityireland.ie/projects/additional-survey-schemes/backyard-biodiversity/species
Bat Monitoring and Distribution Projects	Bat Conservation Ireland	Bats	https://www.batconservationireland.org/what-we-do/monitoring-distribution-projects
Big Beach Biodiversity Survey	National Biodiversity Data Centre and Environmental Protection Agency	Tidal marine species	https://exploreyourshore.ie/shore-surveys/the-big-beach-biodiversity-survey
Big Jellyfish Hunt	National Biodiversity Data Centre and University College Cork	Jellyfish	https://exploreyourshore.ie/marine-biodiversity-surveys/the-big-jellyfish-hunt
Bumblebee Monitoring Scheme	National Biodiversity Data Centre	Bumblebees	https://www.biodiversityireland.ie/projects/monitoring-scheme-initiatives/bumblebee-monitoring-scheme
Hop to it: National Frog Survey	Irish Peatland Conservation Council	Frogs, tadpoles, and frogspawn	http://www.ipcc.ie/help-ipcc/hop-to-it-national-frog-survey-irelandcard
Clean Coasts Programme	An Taisce	Coastal environments	https://cleancoasts.org/our-initiatives/clean-coasts-volunteering
Dragonfly Ireland 2019–2024	National Biodiversity Data Centre	Dragonflies	https://www.biodiversityireland.ie/projects/monitoring-scheme-initiatives/dragonfly-ireland-2019-2024
Farmer's Wildlife Calendar: Climate Tracker	National Biodiversity Data Centre	Weather, climate, and wildlife	https://www.biodiversityireland.ie/projects/additional-survey-schemes/farmers-wildlife-calendar-climate-tracker
Flower-Insect Timed Count (FIT Count)	National Biodiversity Data Centre	Flower-visiting insects	https://pollinators.ie/record-pollinators/fit-count
GLOBE Air Quality Campaign	An Taisce	Air quality	https://www.globe.gov/web/ireland/home/overview-of-air-quality-campaign
Invasive Species	National Biodiversity Data Centre	Invasive species	https://www.biodiversityireland.ie/projects/invasive-species
Irish Basking Shark Project	Irish Whale and Dolphin Group	Basking sharks	https://exploreyourshore.ie/marine-biodiversity-surveys/irish-basking-shark-project
Irish Butterfly Atlas 2021	National Biodiversity Data Centre	Butterflies	https://www.biodiversityireland.ie/projects/monitoring-scheme-initiatives/butterflyatlas
Irish Butterfly Monitoring Scheme	National Biodiversity Data Centre	Butterflies	https://www.biodiversityireland.ie/projects/monitoring-scheme-initiatives/butterfly-monitoring-scheme
Irish Garden Bird Survey	BirdWatch Ireland	Garden birds	https://birdwatchireland.ie/our-work/surveys-research/research-surveys/irish-garden-bird-survey
Irish Hedgehog Survey	National University of Ireland Galway and National Biodiversity Data Centre	Hedgehogs	https://www.irishhedgehogsurvey.com
I-WeBS	BirdWatch Ireland	Wetland birds	https://birdwatchireland.ie/our-work/surveys-research/research-surveys/irish-wetland-bird-survey
KelpRes	National University of Ireland Galway	Kelps	https://exploreyourshore.ie/marine-biodiversity-surveys/kelpres
Ladybird Atlas 2025	National Biodiversity Data Centre	Ladybirds	https://www.biodiversityireland.ie/projects/additional-survey-schemes/ladybird-atlas-2025/ladybird-atlas-2025-2
Leaf Miners	National Biodiversity Data Centre	Leaf mining fauna	https://www.biodiversityireland.ie/projects/additional-survey-schemes/leafminers-survey
LiDAR Public Feature Identification	Geological Survey Ireland	Karst	https://dcenr.maps.arcgis.com/apps/webappviewer/index.html?id=b7c4b0e763964070ad69bf8c1572c9f5
Local Authority Waters Programme	Local Authority Waters Programme	Waterways	http://watersandcommunities.ie/get-involved
National Vegetation Database	National Biodiversity Data Centre	Vegetation	https://www.biodiversityireland.ie/projects/national-vegetation-database
National Reptile Survey	Irish Wildlife Trust	Terrestrial reptiles	https://iwt.ie/what-we-do/citizen-science/national-reptile-survey
ORCA Ireland	University College Cork and Ocean Research Ireland	Marine megafauna	https://www.orcaireland.org/#Citizenscience
Pasturebase Ireland	Teagasc and Dairy Research Ireland	Grass	https://pasturebase.teagasc.ie
People for Bees	Irish Wildlife Trust	Bees	https://iwt.ie/people-for-bees
Project Lapwing	BirdWatch Ireland and National Biodiversity Data Centre	Lapwings	https://birdwatchireland.ie/our-work/surveys-research/research-surveys/project-lapwing
Purse Search Ireland	Marine Dimensions	Mermaids' purses	https://marinedimensions.ie/purse-search-ireland
RECONNECT	University College Dublin	Irish rivers	https://www.ucd.ie/reconnect
Rocky Shore Safari	National Biodiversity Data Centre and Environmental Protection Agency	Seaweeds and intertidal invertebrates	https://exploreyourshore.ie/shore-surveys/rocky-shore-safari
Seasearch Ireland	National Biodiversity Data Centre	Inshore marine biodiversity	https://seasearchireland.ie
Seashore Snapshots Survey	National Biodiversity Data Centre and Environmental Protection Agency	Barnacles and limpets	https://exploreyourshore.ie/shore-surveys/seashore-snapshots

(Continued on following page)

TABLE 2 | (*Continued*) Citizen science projects in Ireland in 2020.

Project name	Host organisation	Study subject	Website link
Seashore Spotter	National Biodiversity Data Centre and Environmental Protection Agency	Seashore marine species	https://exploreyourshore.ie/shore-surveys/seashore-spotter
Solitary Bee Monitoring Scheme	National Biodiversity Data Centre	Solitary bees	https://pollinators.ie/record-pollinators/solitary-bee-monitoring-scheme
Spring Flowering Plants Project	National Biodiversity Data Centre	Spring flowering plants	https://www.biodiversityireland.ie/projects/additional-survey-schemes/spring-flowering-plants-project
Waterways for Wildlife	Irish Wildlife Trust	Waterway wildlife	https://iwt.ie/waterways-for-wildlife
Whale and Dolphin Sighting	Irish Whale and Dolphin Group	Whales, dolphins, turtles, and crustaceans	https://iwdg.ie/get-involved
Wild Honey Bee Study	National University of Ireland Galway and National Biodiversity Data Centre	Honey bees	https://www.biodiversityireland.ie/projects/additional-survey-schemes/wild-honey-bee-study

TABLE 3 | Awareness of citizen science across the Irish education system.

Irish education level	Participating educators	Awareness of citizen science (%)
Primary school teachers	50	6
Post-primary school science teachers	114	13
Scientists at an Irish university	157	53

scientists and scientific institutions". While the number of teachers who had previously come across the term citizen science was quite modest, their definitions were broadly accurate (for example, "*Science conducted by ordinary people who are interested in science but aren't professional scientists themselves*" was the answer from Primary Teacher no. 27 and "*Individuals other than scientists taking part in scientific investigations or contributing to scientific projects by gathering data*" was the answer from Post-primary Teacher no. 78). Those at third level, while having a higher awareness level of the term, also offered a number of definitions that would fit interpretations of the terms "science communication" or "public engagement", but were incorrect as definitions of citizen science (for example, "*informing the public about how science issues impact their everyday lives!*" — Scientist no. 59, and "*Science for the layman?*"—Scientist no. 28). These insights suggests that improving the awareness and understanding of citizen science in the Irish education system may be an important first step toward successfully realizing its potential.

FUTURE OPPORTUNITIES FOR CITIZEN SCIENCE IN IRELAND

While the number of national citizen science projects in Ireland is not quite at the same level as some European countries, such as Austria, Spain, or the United Kingdom for example (Eitzel et al., 2017), there is enough capacity and infrastructure within the research and education systems in Ireland that, with appropriate funding and support, Ireland could quickly become a country synonymous with best practice in citizen science. The citizens taking part in citizen science initiatives in Ireland mirror the social demographics seen in other public events in Ireland that focus on science education and science communication. Citizen scientists in Ireland are more likely to be highly educated, close to middle-age, wealthier, more concerned about environmental issues, and have higher levels of employment than the general population in Ireland (MacDomhnaill et al., 2020). This is largely true of any events in Ireland where public audiences engage in science, from large-scale science festivals (Roche et al., 2017) to intimate science comedy nights (Roche et al., 2020b). The most important recommendation for the future of citizen science in Ireland aligns with a key recommendation from the US National Academies of Sciences, Engineering, and Medicine; issues of power and equity should be taken into consideration at all phases of citizen science project development and implementation to ensure citizen science is as accessible and inclusive as possible for all members of society (Pandya & Dibner, 2018).

Funding Developments

A crucial step toward improving the national capacity for citizen science in Ireland is to capitalize on the increasing availability of funding. Over the past 10 years, funding support for citizen science across Europe has risen, particularly through Horizon 2020—the research funding program of the European Commission. The European Commissioner for Research, Science and Innovation, Carols Moedas, highlighted the openness and accessibility of science as "an increasingly crucial ingredient" to the vision of scientific research being "open to the world" (Ramjoué, 2015, p. 167; Moedas, 2016). This signaled a change in how citizen science was discussed in policy documents and funding programmes and the European Commission subsequently highlighted citizen science as an approach that, in giving "citizens a greater role in science", could "deliver the vision of science for the people, by the people for Europe" (European Commission, 2015, para. 4). In successive "Science with and for Society" (SwafS) work programmes of Horizon 2020, the term "citizen science" went from being entirely absent from the 2014–2015 program, to being mentioned five times in the 2016–2017 program, to being present throughout (60 times) the 2018–2020 program. This increased focus on citizen science resulted in €58.3 million being invested in 22 large scale citizen science projects across Europe so far, with more likely to be added (Warin and Delaney, 2020).

While the specific portfolio of "Research, Science, and Innovation" was functionally discontinued in 2019 when Mariya Gabriel became the European Commissioner for a new portfolio of "Innovation, Research, Culture, Education and Youth", she recognised the significant contributions that large numbers of empowered citizens have made to scientific progress and committed to continuing European level support for citizen science (Warin and Delaney, 2020). An additional important mechanism for developing citizen science collaborations in Europe are "COST" (European Cooperation in Science and Technology) actions, which provide invaluable funding opportunities for establishing research networks. In particular, the COST Action CA15212 ("Citizen Science to promote creativity, scientific literacy, and innovation throughout Europe") provided the opportunity for researchers to work together on pan-European citizen science efforts such as establishing a research agenda to investigate the role of citizen science in education and learning (Roche et al., 2020a) and to make policy recommendations regarding sustainability (Sauermann et al., 2020).

International Opportunities

The US has played a leading role in modern citizen science. The National Academies, for example, highlighted the great potential of citizen science to enrich education systems (Pandya and Dibner, 2018). While there have long been calls to research how culture and language can affect learning in citizen science (Bonney et al., 2009), the benefits of citizen science to education systems and wider society are being actively investigated by a number of relatively recently established international citizen science associations. Most prominent among these are the Citizen Science Association (a US-based organisation with a global membership), the Australian Citizen Science Association, and the European Citizen Science Association (Storksdieck et al., 2016; Roche and Davis, 2017). The European Citizen Science Association's "Ten Principles of Citizen Science" (ECSA, 2015) and "Characteristics of Citizen Science" (ECSA, 2020) offer guidance to the field on how to recognise and classify citizen science. The European Citizen Science Association is also coordinating one of the most wide-reaching citizen science projects funded by the European Commission: EU-Citizen.Science. This online platform and mutual learning space will serve as a hub for citizen science and represents an ideal platform to connect the various networks and citizen science projects in countries across Europe.

Future Directions for Citizen Science in Ireland

A traditional shortcoming of citizen science in Ireland—that the various networks are not linked with each other and need to be connected to better share expertize and resources (Donnelly et al., 2014)—could be addressed through the fledgling EU-Citizen.Science platform. It presents an ideal space for grassroots initiatives across Ireland to find a home where practitioners can remotely connect with like-minded citizens and initiatives, particularly in the post Covid-19 pandemic era. As previously noted, most of the ongoing national citizen science projects in Ireland are either run or supported by state bodies. To increase awareness of citizen science and to align with the commitment to support citizen science at European levels, the Irish government should adopt an official policy on citizen science that sets out how the field will be supported and developed to improve the lives of Irish citizens. Such a policy could utilize citizen science to help Ireland with the dual goals of becoming more aligned with the UN's Sustainable Development Goals (Fritz et al., 2019) as well as strengthening trust between science and society, which will be more vital than ever in a post-pandemic world (Provenzi and Barello, 2020). This may be possible with the newly established Department of Further & Higher Education, Research and Science, where there is, for the first time, a specific and particular focus on research funding and capacity to publish new policies related to such endeavors. Ireland is facing a critical point in its engagement with citizen science. With the involvement of key organisations, government support, and international partnerships, Ireland has the potential to mirror the global trend toward embracing the transformative opportunities of citizen science and usher in a new golden age of science that focuses on participatory approaches and the empowerment of Irish citizens.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Trinity College, Dublin. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JR and ANS led the conceptual design of the manuscript, while PM designed the original approach to cataloging citizen science in Ireland. GLB, LB, and CR carried out subsequent analyses and developed individual subsections of the paper. All authors reviewed the manuscript and agreed to its final version.

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Design Thinking as a Means of Citizen Science for Social Innovation

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Members of the public or community can play a significant role in the development of social innovations. When a social innovation is developed involving a scientific approach and the community, there is the confluence of two fields-citizen science and social innovation. Social innovations can be developed through the employment of design-thinking. In this paper, we advocate design thinking as an approach to marry the two fields for a desired outcome of improved community life in ageing housing estates in Tokyo. The two fields, citizen science and social innovation, are described in brief before the design thinking method is introduced and its utility in engaging citizens for social innovation is explored. The paper provides two case illustrations and the lessons drawn from them. We conclude with pointers for others who desire to employ this approach. When the resultant innovation and design-thinking approach are adopted by the community for future projects, there could be a change in society and possible forward movement for self-help and change.

Keywords: citizen science, design thinking, social innovation, citizen persona, citizen intermediary

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INTRODUCTION

Citizen science has made relevant the work of scientists as it involves sections of the community and public in the activity of science (Irwin, 1995). Citizens have been engaged in a variety of scientific projects; for example in ornithology (Bonney, 1996), or scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions (European Commission, 2016, p. 54). With such engagement, members of the public become aware about science. Their involvement promotes greater interest and a potential increase in scientific activities. There is an increasing number of projects where citizens participate in contributions typically in the area of data collection. Engaging the citizens in the measurement of phenomena benefits both science and citizens through the discoveries, applications, and policy decisions that the participation of citizens enable.

In addition to the awareness and engagement of the citizens, the citizens benefit from the scientific findings and results by the increase of knowledge or practical consequences that result from the science. One other area citizen science can benefit citizens in a more immediate and direct manner, is when the scientific efforts led to solutions in the form of social innovations, addressing social problems that affect groups of people or communities. Social innovations could be developed by individuals (social entrepreneurs), organizations, or even the community. The development process could involve science or scientific approaches. The science might not be at the level of discovery but at the level of human sciences because in many solutions, there is a need to understand needs and ascertain suitable approaches to address the social problem. It is this intersection of science, citizens, and social innovations, that this paper addresses.

In this paper, it is suggested that citizen science can extend into the realm of social innovation with the citizens involved in citizen science through the design thinking approach. There are two settings where citizen science can take place in the development of social innovations. A scientist (social entrepreneur) could initiate a project which involves the citizens in data collection with the solution that the project envisages being intended for them as subjects of the science. For example, an agriculturist could conceive of a way in which new forms of soil improvement could be introduced in a region. Such a project could involve soil measurements, sample collection, understanding of the farming methods, or sources of irrigation among other things. The community could be enlisted to participate in data collection and to provide the necessary information. At other times, the community could be the scientists in applying science themselves to resolve problems they encounter. The first setting is employed in this paper to explore the role citizen science could play in social innovations. Two projects have been initiated by the lead researcher with two communities where the residents have participated. Accounts of these two projects are presented to illustrate the manner in which citizen science have been employed in developing social innovations for these two communities with design thinking as the methodology.

The paper is divided into five sections. After this introduction, the paper examines the potential for the development of social innovations through citizen science with design thinking as the approach employed. The authors provide two case illustrations in section Projects. The two projects tell of how residents in suburban towns in Japan (citizens) participated in university-led projects by employing design thinking to develop prototypes (social innovations). Section "Contributions of Citizen Science to Social Innovation" describes how citizen science contributes to social innovation through design thinking. In the concluding section, the authors suggest recommendations for the employment design thinking for citizen science.

CITIZEN SCIENCE, SOCIAL INNOVATIONS, AND DESIGN THINKING: ADDITIONAL OPPORTUNITIES

Citizen Science

The involvement of scientist-supervised citizens (laypeople or volunteers) in research with the use of the citizen science tools have been a boom for scientific publications with exponential growth of citizen science publications in indexed journals for the last two decades (Sanz et al., 2021). Citizen science has benefited science and mankind through the projects that have proliferated despite the lack of an agreed definition of citizen science. Eitzel et al. (2017) provided an account of the various terms employed in citizen science across different fields, geographical contexts, that has led to consternation on the part of some scientists who prefer standardization (e.g., Heigl and Dörler, 2017).

Mahr et al. (2018) highlighted the co-production of reflexiveness and dialogue between citizen science practitioners and researchers in a bilateral relationship. Danielsen et al. (2018) focused on inclusion of indigenous and local knowledge in citizen science for innovation from a bottom up perspective. Wyler and Haklay discussed the potential of citizen science to be integrated into university research, but have fallen short to taking reference in methodological approach, such as design thinking. In education, citizen science has been utilized to engage the public via storytelling and visualization techniques (Sforzi et al., 2018). Novak et al. (2018) discussed different forms of citizen engagement with a participation model to create participatory digital social innovation.

Social Innovation

Social innovation is a concept McGowan et al. (2017) traced to a sociologist, Ward (1903). It was employed by an economist, Schumacher (1973) to highlight intermediate technology to solve the social and economic problems of the poor. In more recent times, interest in social innovation arose with the quest for solutions to address social problems. With the myriad social problems, it was realized by stakeholders such as policymakers that creative solutions were needed. Governments and policymakers are often far from the social problems on the ground. Solutions were needed for these wicked problems (Rittel and Webber, 1973); solutions that fit their contexts. More often than not, the development of the solutions called for the mobilization of people. The efforts are not limited to the policy makers or philanthropists. They include social entrepreneurs, bureaucrats, frontline staff, service users, observers, or volunteers (Mulgan, 2007). Social innovations include technology and also frameworks of insurance and healthcare which have a huge impact on society (Drucker, 1985). Efforts in developing social innovation entailed the generation and implementation of new ideas, and the organization of interpersonal activities or social interactions to meet one or more common goals. They could also involve providers of products and services (Von Hippel, 2005) or result from consumer-company interactions (Prahalad and Ramaswamy, 2004).

Of interest to this paper is the involvement of users and the disadvantaged whom the solutions are to benefit. Urama and Acheampong (2013), for instance, report the engagement of the slum dwellers in Kenya. Matsushima and Takahashi (2007) included users and environments, explaining in their article about how social innovation often required a new perspective to clarify the dynamic process in which institutional entrepreneurs come to co-opt and make relational rules with various actors. Similarly, Tanimoto (2012) clarified the emergent process of creating social innovation in collaboration with stakeholders in the local community. Social innovations were viewed as a subset of innovation as were inclusive innovations and grassroots innovations (Tan and Zuckermann, 2019). However, the prior research did not further explore the specific roles and effects citizens could play in social innovation. While they examined the role of communities in social innovation, they did not conceive of them as citizens or citizen scientists. Herein is an overlooked intersection that warrants attention.

Citizen Science, Social Innovation, and Design Thinking

It stands to reason from the foregoing that citizen science can be employed in the development of social innovations.

Eitzel et al. (2017) noted that terms describing citizens include "anonymous, non-identified," "amateur, hobbyist," "citizen," and "citizen/individual citizen scientist." It is telling that they observed that "citizen" was defined as "an inhabitant of a particular town or city; a member of the general public in a defined geographic locale." Hence, when citizens who are members of a community could be engaged in citizen science as "citizens." As to the scientists in citizen science, they noted that the terms employed include "citizen scientist, scientist-citizen, public scientist, community scientist" defined as "individual with formal science training who is actively engaged in the civic sphere and wants their work to both serve the greater good and do so transparently." Hence, a scientist seeking to develop a social innovation could qualify to be engaged in citizen science if members of a community or town participate in providing the information required.

The common ground between citizen science and social innovation is the role of citizens, and more so, in the case of citizen science by definition than in social innovation. A solution could be adapted from one country for introduction in another with the community, beneficiaries, or users coming on board in the phase of implementation. Citizen science speaks of their involvement in science at an earlier phase in the development phase. One bridge that links citizen science with social innovation is the scientific approach employed. In this paper, design thinking is suggested as this bridge. Design thinking is an approach or method in the same mould as another research method a citizen scientist might employ. It has a number of advantages.

Design thinking is a scientific approach to innovation that is human-centered. Design thinking has been applied to resolve social problems and create solutions as applied in many fields. For example, students from Stanford school employed design thinking to help developing regions to create solutions as social innovation projects (Brown and Wyatt, 2010). The method has the characteristics of being user centric, process oriented due to its ethnographic richness in deriving empathy of end users through face-to-face observation and direct interview. The steps in design thinking, thus, include research methodologies common to science. To obtain user inputs, there may be interviews, participant observation, focus groups, or surveys. The engagement with the citizens is evident in scientific methods employed.

Popularized by its use in industrial design by IDEO (Brown, 2008), it draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and their requirements for business success (Brown, 2009). Design thinking research has been discussed in different fields including design (Simon, 1969; Schön, 1983; Buchanan, 1992; Cross, 2006) and management (Martin, 2009). Design has been one area where citizens have been engaged in co-development.

Citizen science can employ design thinking as an approach in social innovation projects. It offers certain benefits. First, design thinking places emphasis on the role of users, the citizens, in projects. Second, it could be employed without using large sample sizes as many design thinking projects involve the target user as a representative of the whole. Third, the community is able to see the output from the projects in the form of prototypes which could take the form of simulations, programme designs, webpages, or mock-ups. Fourth, there could be the adoption of the recommendations for implementation by the community. This is a key reason the authors suggest it as a method that could be used by the various stakeholders to engage citizens in science as the outcomes/solutions can be reviewed by the community for implementation. Fifth, the visibility of citizens, who are peers from the community, implies endorsement by members of the community and there is potential of identification of the other citizens, who are not involved in the projects, with the project or research being conducted.

In the following section, we describe two projects involving citizens in design thinking for the development of social innovations.

PROJECTS

Overview of Projects

In these two projects, the scientist is the first author, who with his student teams worked with citizen scientists, the residents of the two communities, using design thinking to develop solutions to address a social issue faced by both communities: ageing seniors and the need for active living on their part as they age in place.

The projects involve collaboration amongst residents, representatives from the local communities (housing estates one each from two suburban Japanese regions, Kimi No Mori town in Chiba prefecture and Ena city in Gifu prefecture), university student teams, and other external stakeholders. The university student teams comprised international students from Nagoya University of Business and Commerce (NUCB).

Context of Projects

The rapidly ageing population in Japan requires innovative solutions for seniors to lead active lives where they are in their communities. Social innovations are much accepted in Japanese society. They are often driven by formal Japanese corporations such as OMRON Taiyo Home Co., Ltd. with initiative coming from the corporations (Fujisawa et al., 2015), or by social enterprise, such as Hokkaido Green Fund (HGF) for the development of energy business from stakeholders' perspective (Tanimoto, 2012).

The sites for the projects are typical of ageing suburban regions in Japan. These suburbs typically have the ageing towns with typical "fading" signs. Most residents are able-bodied, financially independent, and skillful retirees, who reside alongside some pockets of young families. The towns have relatively good infrastructure but are less accessible to big cities, such as Tokyo or Nagoya, respectively. These suburban regions encompass nature reserves and possess unique cultures.

Kimi No Mori town is about 50 kilometres away from Tokyo and accessible by train or highway. The estate was developed by Tokyu Land Corporation in the 1980s. The uniqueness of each Tokyo Land Corporation estate is the development of a residential area within a golf course, with customized building architecture resembling an American district. Thus, the estate appealed to residents who enjoy exclusive countryside residential and the "overseas" experience. Kimi No Mori has close to 3,754 residents of about 1,485 families. Those aged above 65 years old make up about 24% (899 people). Out of this group (65 and above), 72% were permanent residents, while the rest of 28% are residents but have the intention of leaving. Within the town, there is a group of retired residents who promote an "organic lifestyle and good dietary habits." This group cultivates natural products, such as organic vegetables, organic blueberry, and produces small scale commercial items for sale within the town.

Ena city is larger with about 50,000 residents. It is about 70 kilometres away and about an hour car ride from Nagoya, the most bustling area in Central Japan. One of the unique features of Ena city is that it lies along "Nakasendo" highway, one of the two key routes from Tokyo to Kyoto in the Edo period in the 1800s. It is known as the "49th station" along the Nakasendo highway, where the Emperor has stopped over to stay. There are many facets in Ena's cultural life today - several festivals, activities, art creation, and local products - to mark significant historical events. The "noren" split curtain festival is one such event held annually around October till December. A "noren" is a split curtain that is culturally hung on the door or local restaurants, shops, or even houses as a decoration and identification of the business owner's craft. During the festival, about 200 noren curtains will be hung along the streets in Ena city, as a way of celebration and depict the vibrancy of the city in the Edo period.

Both project sites were selected by the researchers as the "context" for social innovation employing design thinking to explore innovation of new solutions. Within the two projects, four citizens from the local communities participated in the projects as citizen scientists. The roles are described below in section The Role of the Citizens in the Research and summarized in **Table 1**.

TABLE 1 | Samples of citizen science projects.

Case	Case study I	Case study II
Citizen typology	Project in Kimi No Mori town (2018)	Project in Ena City (2019)
Citizen Persona (CP)and role in Design Thinking	Ms Kitakaze Resident and Organic Blueberry Farmer Provide organic blueberry jam tasting experience for student designers Sharing of experience and needs through social media Feedback on final prototype and proposal	Mr Kato Resident and citizen committee head for noren split curtain festival Conduct experiential learning of mini noren contest in class for students Sharing of experience and needs in class Feedback on final prototype and proposal
Citizen Intermediary (CI) and role in Design Thinking	Mr Yuki Hara Committee member in the residents' club Interpret, iterate and evaluate prototype and proposal throughout Design Thinking stages	Ms Naruse Ai Resident and staff of International Exchange Association in Ena city Interpret, iterate and evaluate prototype and proposal throughout Design Thinking stages

Employment of Design Thinking With Citizen Science in Two Communities

Implementation of Design Thinking

The projects were conducted as part of an undergraduate course on design thinking for international students from two cohorts in 2018 and 2019, respectively. The coursework requirement for the course is the development of social innovations to promote active living in the two estates. In phase one of the course, the researchers introduced the student teams to social innovation and design thinking within the classroom environment through case studies. They are instructed on six steps in the design thinking process: "empathy," "definition," "ideation," "prototype," "iteration," and "testing." The student teams were then introduced to the contexts they were to apply design thinking through a series of speakers: the researchers, representatives from the two estates and Tokyo Land Corporation representatives. They presented the facts, problems faced in each estate, current activities, and future goals in the estates.

The second phase involved the students engaging with the citizens in design thinking. With the lectures and speakers, the student teams were exposed to the contexts of the estates and able to empathize with their situation. Through empathy, they were able to identify the needs in the estates before entering the creative step where they think of solution-ideas. They developed the prototypes of the solutions which they would iterate with a few residents before the final evaluation in the form of a presentation before a panel of residents and stakeholders. Local citizens were invited to participate in these three stages, "empathy," "prototype," and "testing" via face-to-face or online connection format. The resident representatives either came to class or participated over SKYPE meetings[1] with ideas from the student teams being presented when they shared their computer screens with the citizens in the SKYPE meeting. The students interviewed and conducted surveys on the citizens as samples of the community at the "iteration" stage.

Those sessions of feedback enabled students to obtain direct feedback from residents and stakeholders to improve the idea and prototype. A post mortem session was carried out between the researcher and the residents directly at the end. The phases and activities are shown in **Table 2**.

The Role of the Citizens in the Research

Two citizens from each city are invited as the engaged citizens. They have volunteered to be part of the design thinking project to support the creation of social innovation that would impact their local community.

The citizens play the roles of citizen persona, the target user of the solution to be designed, and as citizen intermediaries, liaising between the scientists (researchers and student teams), and the citizens. Citizen persona are individual residents from the respective estates who provide information about their situations, needs, and issues faced. In the design thinking approach, "persona" would be a representative on behalf of a population of end users to reflect the background, latent needs for empathy by designers. In addition, citizen persona will access and provide

[1]The features of SKYPE can be found at https://www.skype.com/en/features/.

TABLE 2 | Timeline for employing design thinking in two suburban towns.

Cohort/year	Month	Activity	Action
One in 2018	Feb	Planning for Action Research	Formalization of joint research
	Mar (Phase 1)	Design of content for project for Kimi No Mori Estate"	Formalization of content and system
	April - July (Phase 2)	Implementation of "Design Thinking course-Kimi No Mori Estate"	5 solutions and prototypes were created
		Presentation of outcome to residents	Resident kept the proposal for consideration
		Post mortem lesson discussion Showcase of "Digital Blueberry" video at film festival in university	Feedback Won award for "Community Film" category
Two in 2019	Aug (Phase 1)	Design of content and system project for Ena estate	Formalization of content and system
	Sept- Dec (Phase 2)	Implementation of "Design Thinking course- Ena Estate"	5 solutions and prototypes were created
		Presentation of outcome to Ena residents	Residents were impressed with the proposal. There is strong interest to pursue the proposal. Invitation of students to implement in town
		Presentation of Prototype and solution at noren festival opening ceremony	Attended by Ena city mayor, government officials and residents

local resources which are prescribed as "raw materials" relevant for the solution design.

In Kimi No Mori estate, Ms Kitakaze, in her sixties, a long-time resident, who retired after a successful career as designer for Tokyo Disneyland, is the citizen persona. In her retirement, she cultivates and produces organic blueberries in her own garden with her family. They shared the motivation to create unique organic blueberry jam which is good for vision health, especially for young working adults who strain their eyes working on computers, as well as seniors who have declining eyesight due to ageing. She is entrepreneurial, motivated not to profit, but to create something by using her curiosity to contribute towards her community. In spite of her elder age, she enjoyed posting her activities on social media, such as Facebook and Line. Her motivation for working on the project is to bring more people to her town in the light of the dwindling of activities in Kimi No Mori estate.

In Ena estate, Mr Kato, in his seventies, a male local resident leader of the annual "noren" festival, is the citizen persona. His committee receives fullest support from the city mayor, local merchant association and local schools in Ena city. He is very motivated and receptive to making incremental changes within his means that contribute towards his community. He is not technologically savvy with social media but loved to find opportunities to connect with others. Even though he had past experiences teaching students to make "noren," he has not collaborated with any university on any formal research activities.

Citizen intermediaries are either residents or individuals with connections to the communities in the estates. They act as liaison amongst the scientists (researchers and student teams), the citizen persona and the community at large. In addition, citizen intermediaries will interpret any tacit knowledge, such as experiences and emotions of the residents. They play an important role in the iteration of prototype A citizen representative from each estate is invited as citizen intermediaries into the projects. They are motivated to be the "middleman" to share the narratives and to bring social impact to their respective community.

Mr Yuki Hara, about 30s, Japanese, a committee member in the residents club in Kimi No Mori estate. He does not physically stay in the estate, however has been an active volunteer who regularly homestay and visit the estate due to his close ties with the residents. He has committed to research and implement solutions that promote local participation amongst residents and other surrounding stakeholders, such as schools, universities, and industrial organizations.

Ms Naruse Ai, about 40s, Japanese lady works as a government representative in the International Relation Department in Ena city, within Gifu prefecture. She has joined the organization for about a year and is currently responsible to promote international collaboration between Ena residents and the foreigner residents in Ena city, as well as any external international partners or communities.

Student Teams

The student teams comprised two cohorts of international students. There were 27 students from the first cohort in 2018 and 24 students from the second cohort in 2019. In each cohort, five student teams were formed. The students were mainly business background, undergraduates, however with a few master level and engineering backgrounds. They were mostly not able to speak Japanese and were unfamiliar with the Japanese local communities. They were tasked to develop solutions that promote active living by the elderly communities in suburban areas as their course project. Thus, the students became actors for citizens to effectuate and collaborate through design thinking within the citizen science framework.

Solutions Suggested for the Estates

Solution Selection

The student teams developed a number of solutions per estate. From the developed solutions, two solutions with the highest scores when evaluated by the citizen persona and citizen intermediaries were selected. The selection criteria were the degree of engagement between the residents and the student teams, solution innovativeness, solution implementation feasibility, and the degree of desirability. The residents and stakeholders as beneficiaries rated the solutions on their desirability. The selected solutions are namely "Digital Blueberry" video by Team A from the first cohort for residents in Kimi No Mori estate, and "Harmony Audio" system by Team B from the second cohort for residents in Ena estate. The citizen engagement to create the solutions are summarized in **Table 3**.

Solution I: "Digital Blueberry" Video for Kimi No Mori Estate

At the "empathy" stage, Team A, made up of five international students, tried to gain a deeper understanding of the residents' situation and empathize through secondary sources: the social media and past records about Kimi No Mori town, They were able to gain insights from Ms Kitakaze's video, photographs, and social media posts about her cultivation and sales of organic blueberries. Greater empathy for their idea resulted from tasting Ms Kitakaze's blueberry jam which she delivered to the team.

In the "definition" stage, Team A tested various ideas. They set out to produce a short advertisement which was both informational and captivating for locals and others who lacked a knowledge of Kimi No Mori by using the story of Ms Kitakaze san and her blueberries. They identified Kitakaze as the "Disneyland Lady" from her career as designer of Disney's costumes, in particular, the Mickey Mouse ones. They were inspired to use animation in their video as fit with the youthful and fun theme in Disney and it reflected her past experience and current mindset. An additional inspirational factor was the health benefits that the organic blueberry jam provided in improving vision health. The team found that blueberries was a good message to send as it drew attention to the elderly residents in Kimi No Mori town, and to the good quality organic jam produced there. This message could serve as a bridge for the town to youth groups attracting them to preserve the environment and to eat healthily.

At the "prototype" stage, they decided upon innovative content with a key characteristic. The content would compose a hybrid of both real-life footage and an animated blueberry icon, named "Jerry," which would be included in a storytelling format. The intent was to make the video more youth-friendly and appealing to a wider audience.

During the "iteration" stage, Mr Hara, the citizen intermediary, contributed his feedback to the student team through online interaction during the class and subsequently by email. He highlighted that Japanese viewers would not be able keep up with the conversation in video without Japanese subtitles which he suggested be added to make the video understandable to non-English speaking audiences. Through the repetitive "trial and error" sessions, the prototype video was filmed and created using the "green screen technology" as taught within the course.

At the "testing" stage, Ms Kitakaze, Mr Hara, and a few external stakeholders, who formed the panel of evaluators, viewed the final version of the advertising "Blueberry Jam" video. They were connected using an online and synchronous communication platform, SKYPE in class. Both residents provided additional feedback on how to build social networks to physically purchase the blueberry jam if there was interest on the part of the audience.

Team A leader said "We were fortunate to communicate and received in-depth feedback through Mr Hara, based on the initial prototype and proposal of their project. This proved extremely useful, as it provided a rather unique take and view of the video pointing out areas of improvement we had not even considered."

The "Digital Blueberry" video proposal was evaluated to be one of the most creative solutions. Ms Kitakaze was pleased to consider using the digital movie to market her blueberry jam. Other foreigners in the panel were also impressed and felt a sense of "relationship" with Ms Kitakaze and her product. They were also curious what made Kimi No Mori town such as an "unknown" town that brought "hope" and "activities" to the community.

After the project, a few members presented their digital movie at the NUCB Film Festival to about 100 student audiences. The film won a prize under the "community film" category. The narratives and learnings of the project were also written into three separate case studies registered under NUCB case centre for educational purpose. The prototype and outcomes are summarized in **Table 4** and **Figure 1**.

Solution II: "Harmony Audio" System for Ena Estate

Team B hoped to establish a shared economy in the Ena estate to promote the exchange of data and resources, develop peer to peer relationships, and create economic benefits.

The team received information about Ena-city through local brochures and publicity materials, which enabled them to visualize the town and its surroundings. To further empathize with the residents, Mr Kato gave an introductory lecture about Ena town and "noren" curtains as a Japanese culture. A mini "noren" design contest was organized for the entire cohort, including members in Team B. While making the noren curtain, the team took the opportunity to interview Mr Kato. Through the face-to-face interaction, students could gain additional insights about the needs of the Ena residents, the importance the resident attached to noren and began to identify with the culture.

At the "definition" stage, the team identified the social issues faced by residents in Ena estate. They realized there was a lack of awareness about the attractions in Ena city. The existing publicity materials were static marketing brochures and official websites in Japanese. There was insufficient being done to attract tourists and, as a consequence, lack of awareness about its attraction. Most foreign visitors either did not know about the existence of the city or they did not know what there was to do there in terms of attractions. Thus, Team B decided to focus on these problems. They defined the wicked problem as "lack of awareness about attractions in Ena city and lack of attractive marketing tools to promote these attractions to foreigners."

Through the "ideation" stage, the team came up to designing a map paired with an audio guide as an interactive proposal for locals and foreign users. "Map" with "audio guide" concepts addressed feasibility and innovativeness requirements identified earlier. Maps could be placed in areas with high traffic, so

TABLE 3 | Process of citizen engagement to create solutions.

Lesson	Key content	Design thinking course for Kimi No Mori Estate (2018)	Design thinking course for Ena estate (2019)
1	Understanding design thinking	Context of Kimi No Mori estate by Citizen Intermediary (Mr Hara)	Context of Ena estate by Citizen Intermediary (Ms Naruse)
2	User's empathy	Empathy through Citizen Persona (Ms Kitakaze) (online) Tasting of Blueberry Jam	Empathy through Citizen Persona (Mr Kato) Experiential learning of "noren" curtain design in classroom
3	Define wicked problem	Team discussion	Team discussion
4	Ideation	Brainstorming	Brainstorming
5	Prototype marking	Prototype filming	Application making
6	Iteration	Iteration of prototype with Mr Hara	Iteration of prototype with Ms Naruse
7	Testing (Final proposal presentation)	Evaluation and feedback by Mr Hara and Ms Kitakaze (online)	Evaluation and feedback by Citizen (Mr Kato and Ms Naruse) (Face to Face)

TABLE 4 | Social innovation through design thinking.

Projects	Items	"Digital Blueberry" video	"Harmony Audio" system
Social innovators and prototype	Design team	Team A from first cohort in 2018 (5 members)	Team B from second cohort in 2019 (5 members)
	Background	Diverse nationality Undergraduate level	Diverse nationality Undergraduate level
	Prototype by team	Video that promote and make the organic blueberry jam and its origin from Kimi No Mori town	System that enable tourist to under attraction in Ena city via QR-Code system
Outcomes	Educational contribution	Case study registered with case centre in university	Case study registered with case centre in university
	Social innovation	Digital Blueberry Video Presented at film festival and won the "community film" award in the University	Noren Design are used for Noren Festival Presented to Mayor and about 150 residents at launching ceremony of noren contest in Ena city

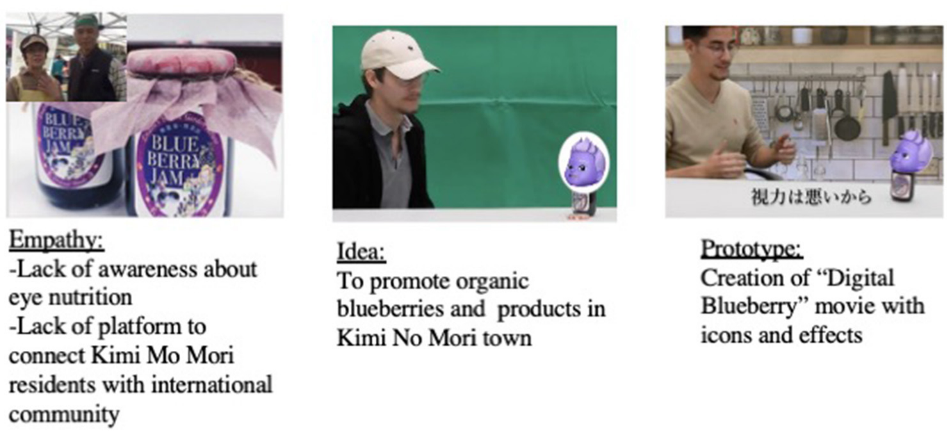

FIGURE 1 | "Digital Blueberry" video for Kimi No Mori estate.

users would obtain information about Ena's main attractions. They could also serve as advertisements in addition to being a useful navigation tool. It would provide an authentic feeling of merging with people, culture and technology to achieve the theme of harmony. Thus, the team named the solution as "Harmony Guide."

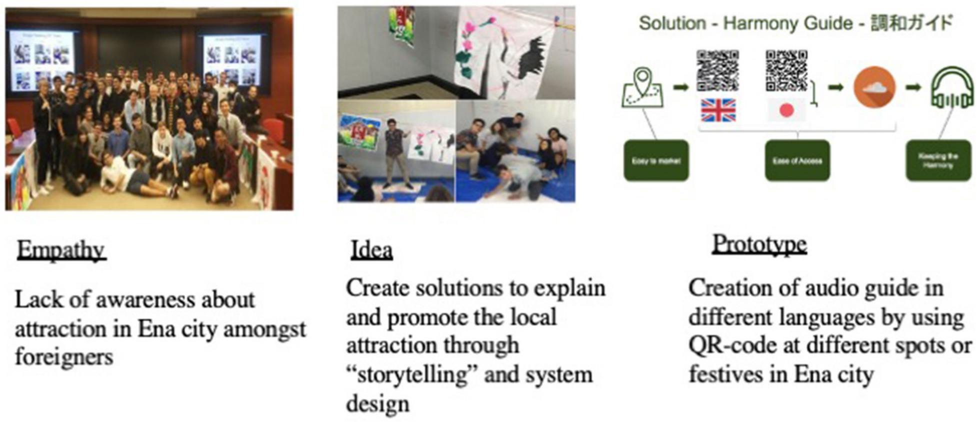

FIGURE 2 | "Harmony Audio" system for Ena estate.

Their first prototype presented to the panel members was the map of Ena city paired with two QR-codes that were meant to direct tourists to two versions of an audio-recording. One version of it was made in English, the other one in Japanese. Both of them contained the same information - explanation about the background of "noren" curtain and other Japanese crafts. Each member contributed by making audio-recordings in multiple languages.

After the "iteration" stage, on behalf of Mr Kato, Ms Naruse provided language translation and interpretation to relay comments to improve the prototype via email correspondence and the messenger application. The team created a second version of the "Harmony Guide" prototype after the additional comments. They developed an extended location map that highlighted local restaurants and local inns, more languages and background music with Japanese instruments. At the "testing" phase, Ms Kato, Ms Naruse, and 2 other invited stakeholders formed the evaluation panel to select the "Harmony Guide" system as the most desirable solution out of the five proposals the cohort developed.

Beyond the project, Mr Kato invited key members in Team B to showcase their prototype and proposal plan at the opening ceremony of the annual "noren" festival held in Ena city. The solution was demonstrated and presented to the city mayor and about 150 residents. The project was written and published into two business case studies registered under the university case centre for academic discussion and research purpose. The prototype and outcomes are summarized in **Table 4** and **Figure 2**.

CONTRIBUTIONS OF CITIZEN SCIENCE TO SOCIAL INNOVATION

The Kimi No Mori and Ena examples illustrate the manner in which citizen science and social innovation intersect. They also highlight design thinking as a methodology which enables both fields to work together and where the goal of citizen science is the alleviation of a social problem. This section details the contributions that arise when design thinking, citizen science and social innovations are employed.

Employing the design thinking approach in citizen science produces a positive impact on student teams. It enables the creation of innovative solutions, as well as the development of a citizen driven model which could be implemented by the community in the future.

Induced Creativity of Student Teams and Social Innovation

From the social innovation perspective, the students felt more "motivated and inspired" to deal with real life cases and real people, rather than fictitious characters and narratives from textbooks. The students gained the ability to develop their logics through the two-way interpretation and collaboration with citizens, in order to create the solutions that are desired by the communities.

Benefits of Design Thinking to Citizen Science

Design thinking is a useful approach because it extends several opportunities for citizen science to occur. Firstly, where science is often associated with sample sizes and large data, design thinking permits experiments to be conducted employing fewer data points. With reference to the two cases, instead of having to identify a large sample of residents, the key appointed citizens (persona and intermediary) may participate in the provision of a new service so as to design the new service. Design thinking permits the scientists or policy makers to explore the options in the development of a new solution to obtain primary data as initial analysis and to consider conducting massive surveys if the solution is deemed feasible.

Secondly, design thinking permits small experiments to be conducted. Experiments of this nature are less costly compared to mounting a full study. Part of the costs are borne by the citizens who volunteer their time and efforts. In contrast, in late scale scientific studies, participants might have to be provided with incentives. In the studies, citizen personas provided the local resources as "raw materials," such as provision of blueberry jam by Ms Kitakaze and "noren" curtain materials by Mr Kato, in order for students to have physical experience to empathy and induce the latent needs of the citizen within a small scale experiment. The creation of two-way communication via formal emails and informal social media platforms have also enabled the collaboration with minimizing any preliminary fieldwork transportation and hospitality expenses.

Next, the value of these small experiments extends beyond the experimentation, whereby the results of such experimentation is the prototype, the solution. The prototype could be a simulation, a mock-up, a program design, a web page, or a model. The advantage is that the solution is made tangible and visible to the citizens for their iteration and testing. There is proof of concept which has a major significance if adoption of the innovation is intended. In the studies, the proof of concept for both "Digital Blueberry" video and "Harmony Audio" system were ascertained at the "iteration" and "testing" phase for a minimum of two rounds involving the citizen involvements. Social innovation is achieved at the points of proof of concept, while adoption of the two solutions are pending at the end of experiment.

There is the advantage for subsequent citizen scientific endeavours because of the endorsement by the citizens who participated. Their account of their role in the study would encourage the participation of others. The presence of a member from the local community having participated in a project that has potential benefits, will resonate with the rest of the community. There is the promotion of such activities through word of mouth. In the studies, arising from the endorsement of "Harmony Audio" systems by Mr Kato and Ms Naruse, the proposal and prototype were presented to the city mayor and more residents at the "noren" festival opening ceremony. Similarly, the contribution and value of the "Digital Blueberry" video has won the "community film" award in the film festival organized by the university and watched by about 100 student audiences.

Finally, design thinking provides a means to enlist student teams and others who are trained in the methodology as the scientists in citizen science. With citizen science being engaged in social innovation, it would enable the possibility of scaling up efforts with the solutions developed being contextualized to their sites and needs of the citizens, as student teams could be deployed. Furthermore, in harnessing the online solutions such as SKYPE, distance does not hamper any of these efforts.

CONCLUSION AND RECOMMENDATIONS

From the foregoing discussion, it can be seen that there is merit for citizen science to consider adding design thinking as a methodology where the citizen science activities involve the development of solutions for community needs. The two projects illustrate how design thinking enables two fields of enquiry to operate and produce satisfactory outcomes for the two estates. They make a strong case for design thinking as a means for citizen science to develop social innovations and that citizen science can extend into the realm of social innovation with the citizens involved in citizen science through the design thinking approach.

As to the study itself there is a need to note important limitations and recommendations on how to organize design thinking for future citizen science projects. One limitation is the need to control the influence of cultural differences on the creativity and relevance of solutions for the residents. While it could be argued that the cultural differences mean that there are fresh sets of eyes examining the situation, the countervailing argument would be the lack of empathy that arise because of them. Next, there is a need to consider "post-design thinking" activity to the continuity of the proposal and application of the prototype for sustainability purposes. It is necessary to equip residents with basic skills to continue testing and using the prototype at the local level, with or without the "handholding" by social innovators. Last but not the least is inclusion of appropriate citizen platforms or events, such as town festivals, in order to showcase the prototypes and solutions to the community at large. It would expedite the awareness and even adoption of prototypes by citizens who are ready for social innovation.

Further research is needed to explore the intersection of citizen science and social innovations. There is much that each field can learn from the other to enhance their efforts for the betterment of life for the citizens.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because they contain information that could compromise the privacy of research participants. Requests to access the datasets should be made to goi_hc@gsm.nucba.ac.jp.

ETHICS STATEMENT

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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METHODS
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Citizen Sensing: An Action-Orientated Framework for Citizen Science

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Citizen Sensing, a correlative of Citizen Science, employs low-cost sensors to evidence local environmental issues and empowers citizens to use the data they collect. Whilst motivations for participation can vary, communities affected by pollution frequently have changemaking as their goal. Social innovation is closely aligned with citizen sensing, however the process of co-creating practices and solutions with citizens who wish to shape their world can be highly complex to design. Therefore, our research articulates an action-orientated framework which emerges from a 2-year pan European project by which follow-on communities may replicate sensing initiatives more easily. The authors examine five studies and explore the cross-cutting principles, phases, stakeholders, methods, and challenges which form this framework. The authors argue that whilst data collection and data awareness are crucial to the citizen sensing process, there are precursory and subsequent stages which are necessary to equip citizens to address complex environmental challenges and take action on them. Therefore, this paper focuses on the stages and methods which are distinctive to citizen sensing. It concludes with recommendations for future practice for citizen sensing and citizen science.

Keywords: citizen science, citizen sensing, social innovation, methods, action-orientated framework, changemaking, co-design

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INTRODUCTION

The world is currently facing complex urban environmental challenges. Large numbers of people living together on small areas of land can lead to environmental problems in air, water, noise and land pollution. These issues have detrimental effects on many aspects of human living such as health and well-being, particularly for those most vulnerable. Research demonstrates that air pollution in Europe is responsible for more than 400,000 premature deaths each year (European Environment Agency, 2015). As well as affecting health, air quality also has an effect on the environment and the climate. It is not just air pollution that is a pressing environmental challenge for many, 30% of the population in Europe are exposed to what is defined as unhealthy noise levels (World Health Organization, 2017). Continuous exposure to noise can have detrimental effects, including fatigue or illness from sleep deprivation, increased blood pressure, and a lower level for learning and creativity (European Commission, 2013).

Recently, the emergence of sensing with mobile devices, low cost and Do-It-Yourself sensors, and open data platforms has enabled citizen participation in data gathering using these technologies. Citizen Sensing (Gabrys, 2014; Suman and van Geenhuizen, 2020) has moved from an individual to a collective and transdisciplinary endeavor and has been applied in the field of environmental monitoring, reflecting on the motivations of citizens to sense their environment. Previous research in the field has demonstrated: how participation is made meaningful (Aoki et al., 2017); the negative drivers that can hamper uptake, such as mistrust in information (Kera et al., 2013); the different motivations within communities conducting sensing initiatives (Balestrini et al., 2014, 2015); as well as insights about the role that awareness plays in motivating changes in behavior and policy (Kelly et al., 2012). Participants are often motivated by more than one factor (Raddick et al., 2013; Reed et al., 2013) and changes to motivation can occur over time.

However, there is a growing demand from citizens to engage in sensing as a means to answer their own questions, and gain information using mobile devices or other information and communications technologies (ICT) (Bria et al., 2015). This motivation typically stems from the citizens' acknowledgment that environmental issues, such as increasing levels of air and noise pollution in industrialized cities, have damaging effects on their health and well-being. Although a number of citizens are becoming aware of environmental issues that might affect their health, a study of over 25,000 citizens found that 59% of Europeans did not feel knowledgeable about air quality issues in their country (European Commission, 2013). Consequently, there is a need to both address the environmental issue, to inform citizens and support them in answering their own questions.

For citizen sensing to be beneficial to the those living with environmental issues, it is necessary to not only create awareness from the data that citizens gather but follow it up and apply it. When collaborating with citizens who are motivated in this way, the aim is to maximize the potential for addressing environmental issues through action and changemaking. Recent discourse regarding social innovation in a changing world has begun to explore similar concerns, proposing a more holistic and interdisciplinary endeavor (Light et al., 2017). Citizen sensing is well-positioned to achieve social innovation having the key characteristics to support it, namely, interdisciplinary, transdisciplinary approaches with platforms that enable exchange (Moulaert et al., 2017), however action-oriented processes aimed at change arguably remain understudied in citizen science.

Therefore, this paper presents a framework of an action-orientated process and methods that were developed through a 2-year project. The project explored how citizen sensing enables communities to capitalize on their insight from the data they collect toward identifying and resolving important environmental issues. This research suggests methods which can equip citizens to address complex environmental challenges and furthermore reveals potential avenues to foster sustainable, meaningful and impactful citizen sensing interventions that can lead to social innovation and ideally, systematic transformation. Our contribution should be useful for researchers and practitioners who are looking to deploy citizen sensing and citizen science projects alike.

BACKGROUND

The democratization of data is happening at the same time that there is a widening of opportunities for citizen participation in environmental monitoring. There are several examples where citizen science has been moving toward this more participatory position (Snyder et al., 2013; McQuillan, 2014). This has also been noted in the conceptual development of participatory sensing and the rise of open, low-cost technologies. In this section we describe developments in both citizen science and participatory sensing to articulate the theoretical background of citizen sensing.

Citizen science describes approaches in which laypeople engage in, and contribute to, science; it encapsulates all the various levels of engagement and the ways in which that data is gathered and evaluated (Cooper, 2016). Historically, citizen science projects tended toward a top down, hierarchical design where the experimental protocol is chosen and planned and where the data is for the sole use of professional scientists (Wiggins and Crowston, 2011). However additional models of public participation in scientific research do exist and have been formalized into five categories: "contractual" (communities recruiting professional research); "contributory" (observing and collecting data); "collaborative" (data collection and refining project design, analyzing data, disseminating results); "co-created" (the public and scientists design the inquiry together and share the majority of steps in a scientific process); and "collegial" (non-accredited individuals reaching recognition by field for their research) (Shirk et al., 2012).

Participatory sensing emerged principally from the open hardware and makerspace movements, and the tradition of participatory digital culture (Lovink, 2002; Kluitenberg, 2011; Barbrook and Cameron, 2015) at the same time as the commercial development of the Internet and digital industries. Participatory sensing shares some principles with citizen science and supports projects which exist in the "collaborative," "co-created," and "collegial" areas of the field. It does so primarily by employing everyday digital devices, such as mobile phones, for the public and professionals to gather and evaluate data (Burke et al., 2006). As affordable technologies are becoming more available, these digital devices are being used to empower groups of citizens to collect information on a shared issue of concern, for instance, local air quality. Furthermore, participatory sensing employs elements of citizen science and community-led data collection on mobile online platforms (Reddy et al., 2010). For example, the Air Quality Egg, a device which senses air pollution and includes an app and web dashboard to compare others' measurements; and Safecast, which senses radiation and provides open access to data.

Citizen sensing takes elements from both citizen science and participatory sensing and is gaining traction as a way to explain citizenship and environmental monitoring using sensor technology in digitally advanced urban environments (also referred to as Smart Cities) (Gabrys, 2014). In this context, citizen sensing promotes a concept of "just good enough data" to allow for people to create and understand datasets which are beneficial to them (Gabrys et al., 2016). Pritchard and Gabrys (2016) describe citizen sensing technologies as "*meant to provide a democratic corrective or challenge to the standard processes for monitoring environments, gathering data, and acting on those data*" (335). However, bottom-up empowerment and environmental change through sensing is hard to achieve. Providing the technology alone is not enough to lead people to make change in the world, on an individual basis or as a community (also known as collective action). For example, user engagement studies on the citizen sensing platform, Smart Citizen, a crowdfunded open source platform for environmental monitoring, revealed a number of issues: lack of technical skills among users, difficulties with the usability and robustness of the sensing devices, a perceived lack of social interactions, purpose and motivation among community members, and problems with data reliability and meaningfulness have too often led to user disengagement with the platform (Balestrini et al., 2014, 2015).

Consequently, within citizen sensing, people are becoming more integrated into the creation of data that is meaningful by addressing issues on a local level, therefore making it more relevant to their lives. This can happen in a number of ways including: deploying sensors in their own environment (Kamel Boulos et al., 2011); becoming a sensor themselves by creating data with personal observations and viewpoints (Sheth, 2009; Kamel Boulos et al., 2011; Crowley et al., 2012); collecting indicators that annotate sensor data to make it more meaningful (Woods et al., 2016, 2020b; Coulson et al., 2017, 2018b) and collecting data through crowd-sourcing and processing the data in a collaborative manner (Borges et al., 2016). Additionally, studies found that embedding principles of co-design into citizen science can have action-oriented and transformative powers (Coulson et al., 2018a).

The following citizen sensing action-oriented framework has been developed by building on this background but aims to address the issues around purpose and motivation of concerned citizens who wish to tackle environmental issues. The following section describes the framework and the iterative development process. It also describes the cross-cutting principles that underpin the framework and articulate the range of key actors which are involved during the stages.

A FRAMEWORK FOR ACTION-ORIENTATED CITIZEN SENSING

The framework was developed through three stages, the first, a theoretical model was proposed following a literature review of the existing practices in citizen science, participatory sensing and citizen sensing. The second iterated upon the first stage using findings from studies of real-world citizen sensing project activities. The final version was validated using a co-designed approach to support collective aggregation during a reflection workshop with the entire delivery team, which included representatives from all participating organizations across Europe.

In the first iteration of the model, the project initially drew on the small number of existing process frameworks in the fields of citizen science (Winner, 1999; Hassen et al., 2015; Bürger schaffen Wissen., 2016; Henriquez, 2016; Jiang et al., 2016). The purpose of the first iteration of the theoretical framework was to underpin the stated aims and values of the project. Earlier framework prototypes provided a baseline process for the project partners to implement citizen sensing activities. As the study was conducted across three cities in Europe, the context and environmental challenge areas naturally differed in each, and this is discussed in more depth in the following section. The final version (**Figure 1**) was devised through a collective aggregation process by the project consortium, led by the authors and in collaboration with the project teams. It sought to interrogate the best practices arising from the project, informed also by participant evaluations of activities, methods and tools, and is used in the discussion to illustrate the elements of the framework. This final framework also draws from existing models of creative problem solving, mainly from the field of design thinking (Design Council, 2007; Sanders and Stappers, 2014; Woods et al., 2015). The co-design workshop where the final framework was aggregated and validated, also underpinned the approach for developing a toolkit for citizen sensing (Woods et al., 2018).

The framework for action-oriented citizen sensing (**Figure 1**) demonstrates an eight-stage process for supporting community action. Although, the discussion describes a linear process, the model describes that each citizen sensing campaign should be considered as a reflective process, with past projects feeding into future work. The intention is that all these stages are achieved in collaboration. To synthesize the framework further, the consortium identified four cross-cutting principles which were evident throughout the process of citizen sensing, and applicable as a foundation for governance and practice delivery, these are expanded below.

Cross-Cutting Principles

Empowerment

An internal state and the feeling of control or responsibility toward yourself and your environment. This can be encouraged with a combination of collaborative approaches and openness in technologies and data that address individual and community issues. This can lead to improved quality of life and greater power for change-making relative to corporations and governments.

Co-creation

A external attitude and the practice of collaborative development and a way to describe an approach in a project using methods and tools for people to work together on a level playing field. Co-creation is a process of jointly using a wide range of resources and ideas for creating new actions and objects.

Change-Making

A process or outcome state, it goes beyond creating awareness of developing purely technological solutions. It involves change in individuals, communities, institutions, and/or cultures, and in thinking, attitudes, values and consciousness. It embraces change led by the community.

Openness

An ambition, this is about the transparency of the organization of the campaign, as well as the data and the actions. This extends to strategic priorities of open design; open science; open tech and data; and an ethos of supporting an increasingly open world.

Stages

The stages of the framework provide an overview of who is involved, what usually happens during that time. The stages also indicate the goals or milestones to reach which, when achieved,

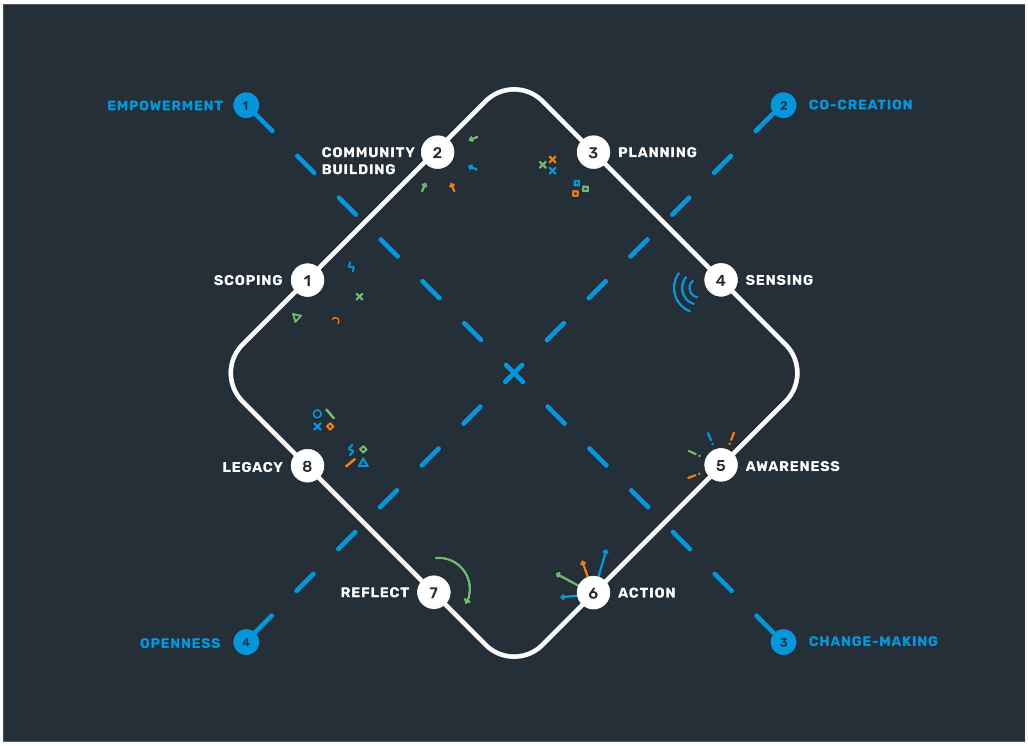

FIGURE 1 | A framework for action-oriented citizen sensing (Woods et al., 2018, pp. 16–17).

signify it is time to move on. Below summarizes these stages and points to the key participants. These participants are described in more detail below the stage summaries. Following this, the paper presents the findings of the case studies, which shine light on some of the specific activities and challenges found in each stage.

- *Scoping* is the first step and the stage when the important issues are discovered, mapped, and discussed by the key participants. Information is gathered by internet searches, collecting articles, news reports and academic literature or by conducting surveys and interviews. This is the stage when existing communities are found, and new ones start to form. There is no time limit on scoping; it can take only a few weeks or can be something that takes years.
  Key participants: community organizers; project teams; community members.
- *Community building* brings together everyone around an issue. The aim is for all participants to come to a shared understanding of the issue and decide on the goals of the campaign. It is when then the skills of the participants are identified and new skills are developed, and it is also when others are brought on board if there are any skills or expertize missing. Participants collectively agree on the organization of the project and how to document activities.
  Key participants: community organizers; project teams; community members.
- *Planning* is when participants collectively decide on the goals for the project, sensing strategies and protocols for collecting data. This includes a plan for collecting other types of indicators. It is when the sensing tools are created or developed from existing resources. Sensors are tested and calibrated. Participants learn about sensors and are introduced to approaches for understanding data.
  Key Participants: community organizers; project teams; community members.
- *Sensing* is the phase in which everyone collects data on the issue, i.e., pollution. The data can be uploaded to a publicly accessible online platform. Participants can also record observations about their lives and how they are affected by the issue. Note taking and collecting indicators is important as this information can support the findings of the sensor data and be used to show the impacts of the issue to other people and government officials.
  Key Participants: community organizers; project teams; community members.
- *Awareness* uses the information gathered during the sensing phase, the data is analyzed and discussed amongst the community. The analysis stage can include optional activities of data visualization; professional science or academic support. The aim is to build a collective awareness from the data. This includes an assessment of the personal observations and the other indicators collected as part of the project. Bringing together all this information is important for identifying potential areas for action and change.

Key Participants: community organizers; project teams; community members; data visualizers; external experts.

- *Action* happens once there is a collective awareness on the issue at hand, participants work together to propose possible courses of action. The aim is to devise, organize and deliver a single or series of actions as a group that may generate a wider recognition of the issue. Actions can range from behavioral change of an individual, to public facing activities (i.e., a public intervention) aimed at creating further awareness or even a policy change. The aim is to have impact and make change for the better.

  Key Participants: community organizers; project teams; community members; media outlets; government officials; the public.
- *Reflection* is when participants reflect on the process to date and consider what worked and what did not. This can include looking at the data and seeing if there was change as a result of the action. This might require the participants to repeat or go back to previous phases, such as sensing.

  Key Participants: community organizers; project teams; community members.
- *Legacy* is created by looking toward the future of the project and planning for lasting impact. It should also include planning for sharing information and news to make sure there is sustainability and reuse of the project tools and the uptake for others. For those community organizations, it is a phase of writing reports and publications and for sharing the project assets that might be useful for other initiatives.

  Key Participants: community organizers; project teams; community members; academics, and external experts.

Key Participants

Within each stage, there is reference to key participants. This categorization of key actors in each stage can help to initiate activity but may also support the management of activities and move the process along.

The key actors involved are:

Community organizers who champion the activities of citizen sensing project to a wide audience. They also facilitate the process and organize the delivery of activity.

Project teams are a collective of key individuals who support the majority of the citizen sensing framework.

Community members are the citizens who are actively involved. They form a community through a shared interest in the environmental challenge which they find pressing. They are also the lead instigators in the actions for change as a result of their newly acquired knowledge from the sensing activities.

Data visualizers are brought on at certain points in the framework in order to help visualize the data that has been gathered about the environmental challenge at hand.

External experts are also brought it a certain point is the process to support the development of skills for the community member, for instance, in training them to calibrate sensors and collect data. They can also be brought in to support the understanding of data, during the awareness phase where they can support community members in making sense of the data they have collected and what other indicators may have an impact on the information gleaned.

Media outlets can be social media platforms or more conventional means of information dissemination (i.e., newspapers, TV and radio).

Government officials are the public authorities who advise or contribute to policy change and can instigate wider impact of change.

The public is the notion of everyone outside the core participant group, it is important to engage the public at certain points in the process. Specifically, during the initial scoping phase insights are gleaned from a wider range of citizens and citizen sensing is driven by a concern of a critical problem. The first step is to identify the individuals or communities which have like concerns and work collaboratively to help identify and develop a deeper understanding of what those concerns are.

RESEARCH APPROACH

The research draws on five case studies, which were instrumental in the development an action-orientated framework to citizen sensing. As previously mentioned, the five studies were designed to examine how open-source software, open-source hardware, digital maker practices and open-source design could be used by local communities to create their own sensing tools to examine their environments and address pressing environmental problems. The studies spanned citizen sensing activities in three cities in Europe: Amsterdam (The Netherlands), Barcelona (Spain) and Prishtina (Kosovo). The studies were driven by co-creation principles and citizen-led, however it should be noted that funding is a crucial resource in the development of many citizen sensing projects, and all of the case studies were part of a wider European Commission Horizon 2020 funded grant.

The consortium collectively developed the research design and protocols and defined the planning, delivery and evaluation of the studies. The data collected through in-depth case studies formed the foundation for this research. The case studies were conducted to answer the following questions: (1) How does the process of citizen sensing manifest itself? (2) What tools and methods support the process toward action-orientated outcomes as defined by participants? The lead authors conducted the research in collaboration with project teams who facilitated and supported the communities for each of the case studies. Discussions between the researchers and project teams followed the completion of this information to ensure comprehensive and cohesive data capture across the studies.

Table A1 in Appendix outlines the case studies examined in this research. It includes the duration of each case study, namely, the time which the project team was active in facilitating the process. However, this does not include the months or years that went into preparing the cases or the ongoing activities in which communities continue to participate in these areas. The table gives an overview of the number of community members involved, who were mixed in gender and aged between 18 and 80. It also illustrates the number of events from each study, including but not limited to the weekly group meetings amongst the project team and community members.

The case studies operated in different context and varied in focus. The summaries below provide more details and the ambitions of each case study:

Case A—A total of 25 local residents measured air quality in small geographical location in the city of Amsterdam. They used existing information from the Dutch environmental defense organization (Milieudefensie) which stated that the Valkenburgerstraat and the Weesperstraat in the heart of Amsterdam were the most polluted streets of the city. Sensors were deployed in and around the residents' homes and collected data on NO2, particulate matter, humidity and temperature. This data was analyzed and interpreted in collaboration with experts and residents. Once the residents had the results, they organized a meeting with the Municipality to discuss the issue of air quality in their area. In addition, they worked with The Lung Foundation to create a campaign about air quality in the city and how citizens can find information about air quality in their post codes.

Case B—Prishtina is one of the most polluted regions in Europe. Citizen sensing was employed to investigate air pollution by empowering young people and affected communities to jointly break the institutional silence around air pollution through evidence-based campaigns and actions. For this case, a committee of young people aged 17–30 were recruited to plan, organize and run a pilot. This committee collaboratively designed the measurement strategy as well as the actions and protests that were arranged in response to their findings. The media coverage of this case was a significant outcome, mainly due to campaign actions which generated a public discourse never seen before in the country. As a result, for the first time, the Kosovo Environmental Protection Agency started to regularly publish their data and policy-makers committed to changes in the constitution that included the citizens right to clean air.

Case C—A second pilot in Prishtina had the same committee members as previous activities, as well as the same collaborative and participatory process. This time, air quality sensing was focused on areas around aging power plants. This pilot covered the spring and summer season, where the previous pilot covered the autumn and winter so that measurements were taken at all seasons throughout the year period. The sensing activities also included the measurement of bio-indicators, mapping lichen diversity as an indicator of environmental stress. An important outcome of this case was the way it which it demonstrated that citizen sensing had become embedded in the culture of Kosovo as a movement, and had evolved beyond the activities of the study.

Case D—This case took place in Barcelona where citizens tested technologies and methodologies in citizen sensing which focused on supporting the understanding of data. The pilot examined noise pollution in the city, as this had been deemed the most pressing challenge by the community organizers, project team and community itself. As a result, the citizens formed into a cohort of 25 community champions who gained a shared level of understanding of the sensing process, methods and skills which they could subsequently pass on to the citizens participating in Case E.

Case E—The Plaça del Sol in the area of Gràcia, Barcelona has historically suffered from people loitering, drinking and creating high levels of noise in the neighborhood. The project team and community champions from Case D, collaborated with the local residents to evidence the problem. Equipping residents with the technology and through an initial iteration of the citizen sensing framework. As an outcome, the community members and project team formed a citizens' assembly event in the Plaça del Sol to bring attention to the issue and share their findings with a wider audience. This event received significant international media coverage, including articles and interview with the citizens. This case leveraged the community members voices and they were able to speak out on their ongoing problems with noise pollution and get the recognition from media and government that they needed to take steps toward resolution.

Once all case studies were completed they were analyzed by the research team. Themes around process, methods, outcomes where gathered and evaluated using comparative analysis. This highlighted the similarities and differences from each case and how the research questions on processes and methods had developed over the 2-year project period. The cases were presented back to the project partners and through a co-design workshop the cases were compared against the initial framework and iterated on to create the final action-oriented framework for citizen sensing. The following section extends the discussion on the final framework. The authors describe the stages, but primarily the methods that are used in each stage. In addition, common challenges from each stage are highlighted for those who wish to use this framework.

FRAMEWORK STAGE, METHODS AND CHALLENGES

The following section provides an overview and examination of each stage in the framework. It describes the ways each can be identified and the milestones that need to be achieved in order to move on to the next stage. Furthermore, it provides a selection of methods that were used across the project case studies, often shared, validated and iterated with participants by each case. These methods were defined and developed through the co-design workshop with all consortium partners. Common challenges or pitfalls are also described, with pathways or suggestions on how to overcome these issues. These elements are summarized in **Table A2** in Appendix and presented in further detail below.

Scoping: Summary

Citizen sensing is driven by a concern of a critical problem. The first step is to identify the individuals or communities which have like concerns and work collaboratively to help identify and develop a deeper understanding of what those concerns are.

Scoping: Methods

Scoping activities can help map out the issues of interest and the work that has gone before, both locally and internationally. This stage can include a literature review on the subject, group meetings open to the public or with targeted groups and experts.

- *Geographical mapping* visualizes the issues of concern during collaborative workshops. This is aimed at finding the existing grassroots organizations (i.e., neighborhood association to citizen movements, NGOs and cooperatives) which are mapped to understand the landscape to examine the linkages and where the gaps remain. It discovers the pressing environmental issues and where things are happening. It also allows participants to understand how and where the critical problem may be affecting them and to speak to others about the issues. For instance, during *Case D*, a community mapping activity resulted in a database of 274 community groups which were categorized by emergent themes: environmental, social, infrastructure and services, cultural, educations, economical, health, and politics.
- *Commons mapping* supports the sharing of resources and motivations for joining a citizen sensing endeavor. It stems from the notion that everyone has something to contribute (i.e., time, skills, resources, or networks). Collectively creating a wealth of potential resources from the outset and fostering a culture of sharing within the project.
- *Collaborative delivery schedule* fosters investment and motivation into citizen sensing. Participants are more invested and willing to drive activities they have devised themselves. Devising the delivering schedule in a collaborative way supported ownership within the cases and the participants would feel more empowered knowing that they had formed the project from the start.

Scoping: Challenges

It is important to understand the local situation, as understanding the culture and motivations of the citizens and their communities is important in creating successful change. Finding out other organizations which have carried out similar activities in this area ensures that this work is built upon, rather than starting from scratch, replicating activities, or encountering similar pitfalls.

Community Building: Summary

There is value in bringing together citizens who have distinct motivations and skills: for e.g., community of concerned residents working a community of makers. Community building is essential to citizen sensing as it revolves around people coming together to tackle a challenge or concern. The process of community building identifies and defines the shared voice and values which guide the citizen sensing campaign. Fostering community cohesion and communication is crucial to the sustainability of the community throughout the process. Community building is also about developing relationship between various people (i.e., experts in the field and government officials) who can support changemaking as the project evolves.

Community Building: Methods

Engaging and recruiting the community will involve forming the issue, tapping into a desire to participate, building a time timeline and an understanding of the process, as well as forecasting what might occur along the way.

- *Recruitment* and the strategies for finding participants can be varied and also applied to different context. There is no one size fits all approach to recruitment, as it is highly dependent on context (cultural, political, social and economic) and the intentions of the community itself. Within *Case B*, the community organizers sought to recruit people between the age of 18–25 to harness the potential of the youth population. To achieve this, the organizers created a mixed method approach to recruit young activists, including: participating in youth-related events; reaching out through social media, mainstream media, radio, newspapers and TV; providing a 3-day workshop to introduce young people to citizen science, data collections and campaigning for change.
- *Onboarding kits* are integral to a productive community of participants. The onboarding kit can welcome and guide new participants into the project and the teams as it is comprized of both informative resources and community-building tools. It breaks down the stigma that citizen sensing is just about collecting data.
- *Empathy timeline* (Woods et al., 2020a) encourages participants to look at both sides of the problem and how the team understands their role in it. This method involves asking community members to think about the complexities of the issue at hand. Community members are aware of their own subjective viewpoints of the issue at hand, the empathy timeline challenges this. Reflexivity is achieved by having community members discuss the ways they are affected by the issue, but also the way they contribute to it. This facilitates community building by bringing people together to discuss issues in a way that they perhaps have not done before.

Community Building: Challenges

It is important to plan the management and governance of the project team to determine how the communities will manage themselves. Setting up spaces and times when the team meet is crucial. As is identifying the skills and resources available in a community in order to plan how the group might bring on any missing skills or address any other gaps. This is also a crucial point at which the team should decide on how they want to document the process, as this documentation can provide useful evidence in the formation of arguments in latter stages. The timing of community building is essential and follows the scoping phase but happens before planning the sensing activities. It may also take a long time, specifically when taking into account the skills available in the team and finding new members to fill any gaps. However, community building does not end when planning begins, it extends throughout the life of the project.

Planning: Summary

This stage is focused on preparing the community members for data collection, interpretation, and the resulting action. The decisions made at this stage affect the type of sensing conducted and the kind of data which is collected. The community members have to be prepared for the tasks and through a greater understanding of the research process.

Planning: Methods

The goals of the sensing activities need to be well-defined as it will influence how the collection of data can be achieved. This includes what kind of the data is collected and the methods and tools needed to obtain this information. It is important to note that not all methods of data collection are technology dependent, community members can act as sensors by recording information on their local environment.

- *Community Level Indicators (CLIs)* (Woods et al., 2020b) make the invisible visible. CLIs are objective measurements collected by the community so as to complement the sensor data. These criteria are chosen by the community and reflect the collective goals of the project. In citizen sensing, people sometimes struggle to understand how data is relevant to their lives, or how it is connected to the challenges they face. This is especially true when decisions about what constitutes an important barometer of change are taken in a non-transparent way and do not relate to the community's concerns. CLIs connect the dots between sensor data and real life. They also help those involved to see the impact of their actions by tracking and measuring real change. This process encourages participants to collaboratively choose what information can be collected. This is also an approach that people use after the project to see if, and how, their actions have made a difference. During *Case E*, community members used the CLIs to co-create one or two indicators which could be used for data annotation in combination with the sensor data. The tool was useful in two ways: (1) It allowed community members to overcome a culture of blame and see the issue was not as straightforward as it initially seemed; (2) it gave the community members an opportunity to discuss strategies to make sense of the sensor data and plan approaches to build on the sensor datasets to reveal deeper insights into the problem. One option devised by the community members was to track the number of people present in a public square, where the community was afflicted by noise pollution. One community member achieved this by photographing the number of people in the square from her balcony. She used these images alongside the sensor data, also deployed in her home, to show government officials noise pollution was a real issue. This allowed the community members to evidence that the high level of noise was directly related to the number of the people socializing in the square at night.
- *Sensing strategies canvas* allows participants to co-create a plan for deploying sensors and recording data. It combines expert knowledge of the scientific process with community engagement in the decision-making process. Having experts present and on-hand to advise helps understand what is achievable with the resources available, and how to gather valid data. Tools that help achieve this can include, a sensor deployment map, a calendar for data collection, and sensing strategy cards.
- *Calibration* ensures that collection of data is valid and aligned to scientifically reliable measures. It requires training, specifically for community members who are new to citizen sensing activities. This activity develops technological skills amongst community members, as they become aware of the methodological processes associated with sensing. Community members should be made aware that without calibration, the data of the project is scientifically meaningless.

Planning: Challenges

Working with community members who have varied knowledge using digital devices can be challenging. This is why Planning is an important phase, as it builds capacity of everyone involved and supports a high standard of information. Diverse backgrounds can often mean diverse and varied levels of education and understanding in the scientific process and in data collection.

Sensing: Summary

Sensing is the phase in which the data is collected. The data should be uploaded to a public and accessible online platform. Participants can also take note and record observations about how they are affected by the issue. Collecting these, and other indicators (i.e., CLIs), can support the sensor data and be used to demonstrate the impacts to external individuals and government officials.

Sensing: Methods

The sensing stage and collection of data can be conducted in a variety of ways including through sensors or mobile devices, taking photos, and collection of supplemental information.

- *Open hardware* has been pivotal in democratizing the sensing process. Most commercial sensors are expensive and cannot be altered to accommodate bespoke needs of the project. Developing open hardware for the sensing stage does require technical knowledge, which may be out with the capacity of community members. In *Case A*, the community members wanted to address daily decision when living in a city with continuous exposure to air pollution. The project team, along with experts from the local university, the Institute for Public Health and the Environment and the SenseMakers network developed air quality sensors which were distributed to the community members and use in line with the co-designed sensing strategy. *Cases D* and *E* used an existing open-source sensing kit and platform to capture noise levels in Barcelona. The kit was Arduino compatible and the design files are open-source. It comprised of a sensor shield, data-processing board, battery and a case. The shield contained sensors which measured noise levels, but could also capture air quality, temperature, humidity and light intensity. Once connected to Wi-Fi the senor can stream data to the online platform.
- *Sensing guides* are field guides that keep those who have limited knowledge of technology and the process of data capture on track during a project (i.e., how, what and when things are to be measured). Sensing guides also double as reinforcements for community members to understand basic operation and how to maintain the technology. In *Case E* a series of take-home booklets were developed that demonstrated the sensing process. The booklets were co-designed with community members from *Case D* (which had occurred a few month

prior) who had found that keeping abreast of the sensing process was challenging.

- *Data journals* give data the context, which is needed, but often undetectable by sensors. It captures annotated information, which can discover false-positives and outliers of the data. Within an environmental sensing campaign, community members can make observations of personal and physical effects, that can indicate patterns between the data and affected individuals. It also allows for community members to develop their own understanding of the data and enquire into how they can use this new understanding.

Sensing: Challenges

Sensing is a challenging phase, and support for community members who are conducting the collection of data is critical. This support may come from the project team or expertize may need to be sought elsewhere.

Awareness: Summary

Data should be collected and shared amongst community members. However, in order for them to initiate change, they must understand what the data means. Understanding the data empowers community members. Transparency in the awareness of data can be evidenced to support action at a policy level.

Awareness: Methods

When the data has been collected, it needs to be interpreted. This process will be informed by the type of data that has been collected. The analyzed data is presented in a visual form, which can be easily understood by a wide range of people.

- *Awareness sheet* relates measurements to tangible impacts, which may become actionable responses to new knowledge formed. It helps to make sense of the complexities of the environment issues and how it impacts citizens. For instance, if monitoring air pollution, and awareness sheet supports community members in understanding the health impacts, like what is the legal limits on air quality in their region and how might exposure effect their long-term health.
- *Data discussion sheet* is about understanding the issues around data itself, and initiates discussions on data ownership and notions of privacy, storage management and what other data should be collected as a result.
- *Data dashboards* support the visualization of data, in order it to be more accessible and open for those evolved and further afield. Dashboards should visualize data that can communicate the issues and research questions identified by the community members. Dashboards can be a key facet in developing knowledge and understanding for the community and be a cannon for further action in the project.

Awareness: Challenges

This process of data analysis and interpretation may be within the capacity of the project team or community members. However, it might also need to be outsourced or data visualizers brought in to process the information, or to train others to do so. Data awareness should be conducted as soon as the sensing phase is complete. A quick turnaround can keep motivation high, and the group can use their insights to consider actions for change.

Action: Summary

Action can be the start of policy change or be the first steps to solving the critical concerns of the community. The community members use their insights to achieve the collaborative project goals. It allows for the community members to feel empowered by their new knowledge and to communicate it with others or use it to make a case for change.

Action: Methods

When the data has been collected and analyzed, the process of planning and co-designing actions for change begin. Actions should be community-led but can receive support from project teams and community organizers. Having ideas are devised and delivered by community members increasing the potential impact the action will have on the community itself.

- *Digital presence* allows for community members to disseminate the findings and communicate widely their critical concerns. These can be on existing platforms (i.e., Twitter, Facebook, and blogs) or through a specifically designed website. This presence can serve as a reference to media outlets or government officials and can be helpful in raising awareness and recruiting new community members for further endeavors.
- *Future newspaper* (Woods et al., 2020c) supports the creation of creative action-orientated ideas. By thinking into the future, ideas for the present and pathways to achieve collaborative goals can be devised. This was most apparent in *Case D*, where community members used the future newspaper approach to imagine a world where the data collected was actionable and outcomes were reported on by national media outlets. The headlines generated allowed them to co-design an intervention in a public square, using the sensors and other lo-fi materials to develop a noise box, which could visualize the level of noise, indicating when levels had hit about healthy limits.
- *Co-creation assemblies* are open sessions to discuss and prototype desirable futures. It is important to get a wider range of perspectives by holding this in a public space or inviting external experts, government officials or even project skeptics. Critical issues are unpacked and grouped into subthemes, which form the premise for round table discussions. Applied in *Case E*, the community members organized an event in the geographical area of concern. This was a small plaza, which was often populated by many people and created a lot of noise that affected the residents who lived there. The community members, in this case the residents, facilitated a co-creation assembly to discuss the issue with the people in the square and start a dialogue about the issue of noise in their area. The discussions were captured and added to a report, along with the findings from previous stages that was prepared and delivered to government officials.

Action: Challenges

Actions should be devised and delivered after the data has been collected and awareness has brought forth an understanding of the problem.

Reflection: Summary

A phase of reflection takes stock of what was successful and what could be improved in the future projects. For instance, the use of certain methods and tools could be better placed at different times, or different participants invited for the activities. It is also the stage to review the sensing strategy and data collection, to consider if the hardware could be improved for future use.

Reflection: Methods

Reflection is when community members, organizers and project teams collaborate on developing the sensors and the methods. It is a point where surveys can be distributed to participants to discover whether the process has developed their capacities, knowledge and understanding of citizen sensing, or sensing more generally.

- *Questionnaires* allow community members to share their experiences of the project and understanding of the critical environmental challenges. The surveys also provide for important feedback in developing future iterations of the project. A questionnaire was distributed in *Case D* to identify what was successful and where the tension points were for the community members. These insights were used to develop *Case E*, changing the order in which some methods were delivered.
- *Project appraisal* a more open approach to reflection would be the pilot appraisal, which brings together participants to hold an open discussion around how the project was delivered. Another method for project appraisal used in some during *Cases D and E*, was sticker-dot voting. Methods are printed on cards and participants use sticker-dots to indicate which method they enjoyed the most. This is followed by a conversation if appropriate.
- *Graduation ceremony* is intended to further cement the community engagement between members and the project organizers and project team. Graduating community members feel validated in their achievements and capabilities. Celebrating these as a group solidifies the community and enhances scope for long term engagement, as was noted in *Case D*, many of whom continued to work on future iterations of the project and on citizen sensing activities.

Reflection: Challenges

Deciding when the reflection stage should end presents a challenge, as there are often new insights or outcomes from sensing, or the actions taken. Planning a gathering for key participants helps with closure but also celebrating the achievements of the group.

Legacy: Summary

The purpose of citizen sensing is to make change. This is the stage where the impact of actions can be considered in the long-term. The continuous relationship between key participants is important for legacy and activities can go beyond the project or citizen sensing activities.

Legacy: Methods

Ideally, legacy would be measured by the change in the world which could be directly relating to the activities of the project. This can be achieved in the short-term by keeping track of changes made from outside the community, like policy amendments or change or by making the information and process available through an open-source platform.

- *Storylines* convey a narrative and can take many forms but should be community-led. It will vary on the context of the project but should aim to be powerful stories which convey achievement, empowerment and greater understanding of the projects. Initially, the community members of *Case E* were very skeptical of citizen sensing and what it could do for them in tackling noise pollution. However, community members from a previous project presented their own journey and development of understanding during a public meeting. This helped prospective community members to understanding the inner workings of citizen sensing and also the impact it would have on their lives.
- *Training the next generation* is aimed at having the learners become the teachers and scaling up activities for the future. Training of future generations in about understanding the process of empowerment and how it stems from knowledge, skills and perceptions. This occurred in both *Case C and D*. In *Case C* the community members created a partnership around a local school to monitor the air quality in the area, but also to deliver an education programme from the school pupils, with an aim to develop and recruit the next generation of citizen sensing participants. In *Case D*, the community champions were trained in sensing skills and technologies so that they could support the community members of Plaça del Sol during their sensing campaign.

Legacy: Challenges

Capturing and evidencing legacy is an ongoing issue for many, this spans beyond the boundaries of citizen sensing. It is important to understand this from the start. Having the right processes, methods and ways for documenting the project will be of great help when it comes to demonstrating the legacy of the project.

DISCUSSION

The notion of "quality of life" both for individuals and communities, is integral to our motivation to address environmental issues and climate change. It is in this framing that we see social innovation and empowerment through citizen sensing provide new ideas with the potential to improve quality of life for those affected. The following discussion presents a summary of insights that addresses a growing space defined by civic approaches to technology use and awareness, the capabilities of IoT sensors to track data over time, and the ability to draw these strands together to inform an action-oriented framework for citizen sensing. Although, this could be presented as the operationalization of citizen sensing, the outcome is greater than a new framework to optimize the activity, or citizen science more broadly. It is intended, at the core, to support community activism and an ability to lead changemaking and social innovations for example leveraging communication opportunities with policymakers.

The findings from the five case studies provide insights on specific activities and challenges in each stage of the framework. Namely, that data collection and data awareness are central to the citizen sensing process, and accessibility can be enhanced through sensing guides and data dashboards. Other tools and activities (i.e., data journals and data discussion sheets) deepen understanding of the context of the sensor data, and of the issues around data itself.

The case studies demonstrate that there are precursory and subsequent stages and activities which have proven important to the citizen sensing process if social innovation is to be realized, an often-overlooked area much of the literature. These include citizens being enabled to specify the critical problem and how it is affecting them, singularly and collectively. Similarly, to co-create the plans for the citizen sensing project, combining expert and community knowledge. The social dimension is significant here, to build a productive community equipped to address complex environmental challenges. The step from awareness to action was enabled in the case studies by visualizing the meaning of data and use of futures methods, wherein thinking into the future created pathways to change. Here action is not an end in itself. It is followed by reflection, and legacy, in a trajectory toward change and impact.

This study demonstrates the multiple and significant dimensions of citizen sensing. Crucially, the findings bring to light factors beyond the technology that enable people to make change in the world. These include the discovery of relevance, and understanding of, the way community members are affected by the issue, and how they contribute to it. This is evident in the cross-cutting principles which both address intrinsic and extrinsic motivation, governance and the ambition for a more open and just world. The principle contribution is to enable interventions that can lead to action and change. This action-oriented approach enables communities to become leaders in actions addressing important environmental issues.

RECOMMENDATIONS FOR FUTURE PRACTICE

Research has a vital role to play in supporting an action-oriented approach, particularly when making a claim for change-making. We demonstrate despite citizens taking more interest and control in sensing there is a continued role for engagement of scientists and researchers in the trajectory toward change. In each case study there was specialist science input, the ability to translate citizen concerns to questions and strategies is a specialist role, as is the development of technologies and platforms to support activities, and visualization of data.

We provide the following additional brief recommendations for research to support citizens who wish to shape their world, these points are categorized for consideration under community and researcher.

Community

- Communities may be living with the environmental issue over an extended period of time, its relevance to them does not begin or end with the research study.
- It important to account for the social dimension of the co-creation process when planning community engagement.
- The first step to communities building ownership around data and technology is their relevance to building evidence around the environmental issue.
- Enable citizens and communities to become leaders in actions addressing important environmental issues.
- Other benefits–not just environmental sensing, learning skills, feeling empowered, seeing change in the community.

Researcher

- Change needs to be supported and provided for from the outset, these are the steps to do it through.
- Privilege action in the moment over the long tail of research, and tangible outcomes for the community over concerns internal to the research community.
- Technology and data are not the panacea—respond to communities' needs not solely through technology use.
- Data collection and awareness practices are enhanced by activities to deepen understanding of the sometimes-subjective nature of the issue.
- Pathways to change and impact are opened by enabling the step from awareness to action.

CONCLUSION

These insights and recommendations can be of value to researchers and communities who are looking to deploy citizen sensing projects to effect positive impact. They complement recommendations developed for action-orientated citizen sensing and for the fields of citizen sensing and citizen science looking to make real change with research impacts.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by WAAG Society. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

SC provided the initial outline, content of the paper, finalized the paper, and content for submission. MW provided feedback during the paper development and at the end. Both authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomm.2021.629700/full#supplementary-material

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REVIEW
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Ethical Issues with Using Internet of Things Devices in Citizen Science Research: A Scoping Review

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Digital innovation is ever more present and increasingly integrated into citizen science research. However, smartphones and other connected devices come with specific features and characteristics and, in consequence, raise particular ethical issues. This article addresses this important intersection of citizen science and the Internet of Things by focusing on how such ethical issues are communicated in scholarly literature. To answer this research question, this article presents a scoping review of published scientific studies or case studies of scientific studies that utilize both citizen scientists and Internet of Things devices. Specifically, this scoping review protocol retrieved studies where the authors had included at least a short discussion of the ethical issues encountered during the research process. A full text analysis of relevant articles conducted inductively and deductively identified three main categories of ethical issues being communicated: autonomy and data privacy, data quality, and intellectual property. Based on these categories, this review offers an overview of the legal and social innovation implications raised. This review also provides recommendations for researchers who wish to innovatively integrate citizen scientists and Internet of Things devices into their research based on the strategies researchers took to resolve these ethical issues.

Keywords: ethics, internet of the things (IoT), citizen science, scoping review, ethico-legal, sensing, smartphones and mobile computing

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INTRODUCTION

This review seeks to identify and address the ethical issues arising from a collision between two innovation trends in scientific research. First, citizen science, or science conducted by non-professional scientists has long been a feature of scientific research. However, in the past 3 decades, an increasing amount of research is being carried out by non-professional scientists cooperating with professional scientists (Cooper, 2016; Irwin, 2018). We understand citizen science to be “an open collaboration where members of the public engage in the scientific process as active contributors, collaborators, or co-creators, undertaking activities similar to scientists” (Shirk et al., 2012, in; Cooper et al., 2019). Secondly, because of the rise in portable and networked computers (henceforth referred to as “Internet of Things”), researchers now have low cost data gathering devices at their disposal. The widespread availability of these Internet of Things tools increases the capacity of researchers to collect and process enormous amounts of data (Rothstein et al., 2015; Auffray et al., 2016). However, scientific projects involving citizen participants may carry a number of ethical complications, including those that may not be immediately apparent to the research team (Cooper et al., 2019). These ethical considerations may be further exacerbated by the ubiquity and massive

TABLE 1 | List of root keywords and synonyms used to search databases.

Keyword	Citizen science	Ethics	Internet of things
Alternative terms	Citizen science, citizen participation	Ethic* IRB	Internet of things, IoR, wearable, web of things mobile device, internet connected, connected device, ubiquitous computing, pervasive computing, smartphone, smart device, sensor

TABLE 2 | List of databases, search strings used for each database and results returned for each search string.

database	Search	Results
IEEE	("Citizen science" AND ethic* AND ("internet of things" OR "IoT" OR "internet of services" OR "wearable" OR "web of things" OR "mobile device" OR "internet connected" OR "connected device" OR "ubiquitous computing" OR "pervasive computing" OR "smartphone" OR "smart device" OR "sensor")	9 results
ACM digital library	("Citizen science" OR "citizen participation") AND (ethic* OR IRB) AND ("internet of things" OR "IoT" OR "internet of services" OR "wearable" OR "web of things" OR "mobile device" OR "internet connected" OR "connected device" OR "ubiquitous computing" OR "pervasive computing" OR "smartphone" OR "smart device" OR "sensor")	122 results
Scopus	ALL ("citizen science") AND ALL (ethic* OR irb) AND ALL ("Internet of things" OR "IoT" OR "internet of services" OR "wearable" OR "web of things" OR "mobile device" OR "internet connected" OR "connected device" OR "ubiquitous computing" OR "pervasive computing" OR "smartphone" OR "smart device" OR "sensor")	455 results
Web of science	ALL=(citizen science OR citizen participation) AND ALL=(ethic* OR IRB) AND ALL=("Internet of things" OR "IoT" OR "internet of services" OR "wearable" OR "web of things" OR "mobile device" OR "internet connected" OR "connected device" OR "ubiquitous computing" OR "pervasive computing" OR "smartphone" OR "smart device" OR "sensor")	36 results
PubMed	((("Citizen science" OR "citizen participation")) AND (ethic* OR IRB)) AND (internet of things OR IoT OR internet of services OR wearable OR web of things OR mobile device OR connected device OR ubiquitous computing OR pervasive computing OR smartphone OR smart device OR sensor)	9 results
Total		631

data gathering potential of Internet of Things devices. Yet, it is unclear how ethical issues arising in such projects are addressed in practice, and whether they are addressed at all. A brief literature research of published studies did not reveal any review of ethical issues in citizen science related to the use of Internet of Things devices.

This paper therefore contains a scoping review of the literature. Its purpose was to analyze whether, and how, ethical challenges for citizen science research involving Internet of Things devices are communicated and handled. Further, this review aims to identify whether researchers in the field are reporting ethical issues and, if yes, what strategies they use to resolve them and what legal implications they mention. Accordingly, this article is split into three sections. The first part centers on the methodology used for this article and describes the scoping review protocol that was used to identify relevant sections of the literature. The second part offers an analysis of the results that address ethical issues in studies combining citizen science and Internet of Things devices, including the legal and social innovation implications. The third part discusses these results in conjunction with existing theoretical frameworks designed to help guide citizen science projects, and offers recommendations for future research.

PART 1: SCOPING REVIEW PROTOCOL

In spring 2020, the authors designed and conducted a scoping review with the goal of retrieving and identifying scholarly literature of studies at the intersection of citizen science and Internet of Things that mention ethical issues. The authors endeavored to include articles describing or discussing an empirical study or project involving citizen science and Internet of Things devices, even if they may be using a different nomenclature. The authors designed and carried out a scoping review by retrieving potentially relevant literature, selecting eligible articles and analyzing the relevant sections (Arksey and O'Malley, 2005).

Retrieval

Based on this research question, the authors defined the following three relevant root keywords: "citizen science", "ethics", and "Internet of Things". These root keywords were used to generate a number of synonymous keywords based on a qualitative exploration of terms used in citizen science research papers (cf. **Table 1**).

The following five databases were selected to search for relevant articles containing a combination of these keywords in any field: IEEEXplore, ACM Digital Library, Scopus, Web of Science, and PubMed. **Table 2** contains the search strings used for each database as well as the number of results returned from each database:

These search strings returned 631 matches in total, which was reduced to 608 results once duplicates were removed. Each of these results was screened by manually examining the title and abstract using the criteria for inclusion and exclusion described in **Table 3**. The inclusion criteria were not applied automatically and the authors did not search to see whether the text contained the words "citizen science" or "citizen participation". For example, a project that described volunteer collaborators was not removed because it simply did not contain a mention of citizen science in the abstract. Instead, the authors manually read each of the titles and abstracts to see whether they matched the screening in or screening out criteria.

TABLE 3 | Eligibility criteria for abstract screening phase.

	Exclusion criteria	Inclusion criteria
Abstract screening phase	In the title or abstract: No mention of a study involving citizen participation or citizen science or any synonymous activity (using the search criteria we had developed above) OR. No mention of internet of things, wearables or other synonymous devices (using the search criteria we had developed above)	In the title or abstract: Describing the enrollment or inclusion of citizens or public participation in a scientific project (this can include synonyms for citizen science, such as “public engagement”, “crowdsourcing” or “volunteer project”) AND. Describing the use of internet of things technology in this citizen science-based study or using a synonymous term from the search criteria above (such as mobile devices, sensors, smartphones, and wearables)

TABLE 4 | Eligibility criteria for full text eligibility phase.

	Exclusion criteria	Inclusion criteria
Eligibility phase	One of the following study designs: o systematic or scoping reviews. Policy or meta-analysis articles attempting to design an ethical framework for using citizen science. In the full text of the article: o only tangential discussion of citizen science (for example, in journal article title in a bibliography) OR o only tangential discussion of ethics OR o only tangential discussion of internet of things or one of the synonyms included above OR o only cursory discussion of ethics approval or ethical issues	One of the following study designs: o a research study report. A research study protocol. A case study or multiple case studies of a citizen science project involving internet of things devices. In the full text of the article: o a substantive discussion of citizen science, such as in the context of a research project AND o a substantive discussion of the ethical issues involved in establishing a citizen science project AND o a substantive discussion of either internet of things technology or one of the synonyms included above in the search terms

Selection and Eligibility

The authors then worked together to assess whether the list of records that they had prepared were congruent with one another and achieved mutual agreement through reflective equilibrium (Daniels, 1996). This resulted in 133 articles screened in. The authors then retrieved the full text and proceeded to the eligibility assessment (cf. **table 4**).

For the eligibility criteria defined above, a substantive discussion includes everything beyond a simple mention of an issue’s existence. Even short paragraphs were included to be as expansive as possible with the search criteria (Crampton et al., 2016). To this end, articles were eligible if they described a specific study design involving active participants. In contrast, study designs where the sole involvement of citizens consisted of them passively contributing data about themselves as part of a survey were not included. Articles that described case studies, or synthesized a research protocol from existing studies, were also included.

After full text eligibility assessment, a total of 34 articles were included as part of the full text analysis. These articles were published across a range of fields between the years 2009 and 2020. All articles were then coded inductively and deductively to identify ethical issues. These ethical issues were then grouped into clusters for an in-depth analysis.

Limitations

The lack of unified definitions for the terms “citizen science” and “Internet of Things” represents a first difficulty when conducting a literature review on these novel topics. One of the limitations of identifying published literature at the crossroad of several novel topics is that the search terms may not have retrieved all citizen science studies that utilized Internet of Things devices and described ethical issues. Further, the decision on whether to exclude or include articles for a “substantive discussion of ethical issues” were not always unambiguous. To mitigate the inherent subjectivity, two of the authors assessed the retrieved articles and reconciled any differences in their eligibility assessment.

PART 2: ANALYSIS OF RESULTS

In this section we address the ethical, legal and social factors raised by the articles identified via this scoping review. Inductive-deductive coding revealed the occurrence of three overarching categories of ethical issues: participant autonomy and privacy, data quality, and intellectual property and labor. This section will discuss each of these issues in turn.

Participant Autonomy and Privacy

Existing ethical frameworks require scientific researchers to guarantee the autonomy and safety of all participants in research. This maxim is usually expressed by the default requirements for researchers to seek explicit, informed and free consent from participants prior to research. A number of results in this sample explicitly addressed this question or sought to guarantee participant consent (Seitzinger et al., 2019a, 2019b; Sousa et al., 2020). For example, Denefleh, in using a sensor device for measuring consumption in a share house, considered whether consent would be affected by the need for housing (Denefleh et al., 2019). Likewise, English et al. discuss the importance of ensuring that citizen science studies do not “fall through the cracks” and avoid ethics review or the need for consent (English et al., 2018). It is also important to recall that much of the existing ethics frameworks for scientific research, such as the Nuremberg Code and the Belmont Report, were developed following unethical and harmful research involving minority populations. Therefore, it is important that scientific researchers working with citizen scientists from minority communities avoid repeating the errors of the past. In particular, Pejovic and Skarlatidou highlight the importance of obtaining free, prior and informed consent when working with indigenous populations. This consent includes a requirement that not only should consent be obtained, but the research goals are conveyed to the community (Pejovic and Skarlatidou, 2020).

Unless the participant has expressly indicated otherwise, it is also important to ensure that the confidentiality of participants is protected. Therefore, a number of studies in this scoping review recommended strategies to maintain participant privacy, including anonymizing or encrypting participant data (Guerrero et al., 2016; Katapally et al., 2018; Acer et al., 2019; Komninos, 2019). As an alternative but complementary strategy, some studies recommended also aggregating personal data submitted by citizen scientists. By using aggregate data, the scientific researchers ensured that individual participants could not be reidentified from their contributions. Further, statistical disclosure controls should be used following the release of anonymized or aggregate data to prevent re-identification from inference attacks (Havinga et al., 2020). Finally, Drosatos et al. and Havlik et al. describe specific algorithmic platforms to guarantee data protection for citizen scientists involved in research. These platforms rely on novel privacy enhancing technologies, such as homomorphic encryption, to protect the identity of participants included in research (Havlik et al., 2013; Drosatos et al., 2014).

Some studies reported excluding some forms of participant data where it was judged to be an inappropriate encroachment upon participant privacy. For example, in Acer et al., the research team supplied Belgian postal workers with Android Wear devices to track their movements upon their rounds. However, these devices not only captured geolocational data but also ambient audio data, which the authors acknowledged represented a privacy concern for both the postal workers and their customers. Therefore, as their study was part of a pilot project, the authors determined to disable this continuous audio sensing functionality as part of future research projects (Acer et al., 2019). Conversely, it may not be possible to obtain explicit consent for all forms of data, such as crowd sourced or volunteered geographic information, or social media data. Havinga et al. suggest that researchers establishing citizen science projects consider whether mechanisms such as geotagging opt in on a social media platform, represents adequate consent (Havinga et al., 2020).

Another issue related to privacy and raised by Sousa et al. is the right to access information about the processing of their personal data enshrined under data protection and privacy law. Several of the studies included in this scoping review suggest extending these rights further to accomodate for specific features of citizen science research. In discussing the results of participants collecting data via smartphones from mosquito traps, Sousa et al. suggest participants should have the capacity to request data about their contributions (Sousa et al., 2020). Likewise, Katapally et al. provide functionality to allow scientific research participants to exercise their right to withdraw from a smartphone based public mHealth study (Katapally et al., 2018). Finally, two of the results, in providing a series of case studies of citizen science projects, defined specific protocols for dealing with sensitive data. These sensitive forms of data can include political opinions or the identity of park rangers investigating controversial ecological issues such as cattle invasions or poaching (Heiss and Matthes, 2017; Pejovic and Skarlatidou, 2020). In a similar fashion, Acer et al. note the importance of ensuring that activity data from workers will not be used against them by their employer (Acer et al., 2019).

Some of the studies included in this scoping review also addressed the more abstract question of autonomy, agency, and why citizen scientists participate in research. Vesnic-Alujevic et al. note that citizen scientists recruited for experiments designed to fine tune wearables for health monitoring are also personalizing devices and actively engaging in their healthcare (Vesnic-Alujevic et al., 2018). Likewise, Seitzinger et al. report how a mobile health app for patients to self-report data on foodborne illness study allowed for more sensitive forms of data collection (such as information on milder illness). Further, the authors describe how this approach helped them to avoid complicating factors around privacy and security for the volume of data usually accompanying big data research (Seitzinger et al., 2019a).

Data Quality and Integrity of Citizen Science Research

Another fundamental principle of scientific ethics pertains to the quality and integrity of research. The vested interests of citizen scientists may intentionally or coincidentally undermine the accuracy and reliability of the data they contribute. A number of the studies included in this sample reported discarding or questioning data due to data quality issues (Aoki et al., 2009; Andersson and Sternberg, 2016; Theunis et al., 2017; Barzyk et al., 2018; Vesnic-Alujevic et al., 2018). The nature of volunteered geographic or crowdsourced information means there can be substantial variances in data quality that are difficult to calibrate in the laboratory (Elwood et al., 2012; Ferster et al., 2013; Havlik et al., 2013; Wylie et al., 2014; Wiggins and He, 2016; Komninos, 2019; Weir et al., 2019).

The retrieved articles also addressed a number of strategies to resolve these issues and guarantee the quality of data. For example, Black and White, as part of an interview study with individuals who contribute air quality readings, note that researchers should consider the implications of "data empowered global citizens". Black and White then report on how interviewees pondered whether they would decide to move from a particularly polluted area if they suffer from respiratory diseases (Black and White, 2016). Another example is the question of how government policy and government-citizen relations may be influenced by citizen science studies. Carton and Ache note that despite criticisms about data quality undermining the integrity of citizen science, citizen sensor networks provide residents with increased "information power" to confront governments (Carton and Ache, 2017). To legitimize this feedback between governments and citizens, Barzyk et al. recommend that government agencies publish guidelines on data quality (Barzyk et al., 2018). Some studies already integrated government standards for data quality into their reporting. Aoki et al. note that in the context of air quality data, California's *Clear Air Act 1967* creates the regulatory framework for air pollution management and standards.

Related to issues about the political nature of data are concerns regarding data bias. Acer et al. note that a majority of data contributions are made by a minority of contributors, which can decrease the representative nature of a sample (Acer et al., 2019). Further, the availability of Internet of Things devices may be comparatively less among older, regional, and minority populations, introducing a demographic or geographic skew in data (Havinga et al., 2020). Likewise, in Yu et al. an entire study was built around addressing deficiencies in data about socioeconomic features of agricultural land systems (Yu et al., 2017). Bias may also be an inherent feature of the data itself, or even exist with the scientific research team processing the data. Heiss and Matthes note that data bias is a particular problem for qualitative social sciences research data, which is based on human perception (Heiss and Matthes, 2017). For crowdsourced data, Wiggins and He note that data from contributors who have previously donated high-quality data may be prioritized over other sources (Wiggins and He, 2016).

In addition to individual and systematic bias, there may be data quality issues associated with the devices used to collect data. In describing how low-cost smartphones and wearables can be used to collect air quality data, Theunis et al. point out strategies that can be used to enhance the usability of this data. These strategies can include charging the battery of the measuring device or turning off the measuring software after use. Further, Theunis et al. describe how more of these measuring errors arise during the later stages of the project, possibly due to decreasing participant motivation (Theunis et al., 2017). Drawing on the literature from human computer interaction, Budde et al. describe how rewards, similar to those used for computer games, can increase participant motivation and guarantee data quality (Budde et al., 2016).

Conversely, the authors in some of the studies included in this review recognized that stringent technical standards of data quality could undermine the purposes of the study. To this end, Aoki et al. report that in assessing air quality, less accurate but cheaper data collection methods could provide useful information on dramatic regional variances in pollution (Aoki et al., 2009). Likewise, Dema et al. suggest that rather than focusing on study protocols, other strategies could be used to improve data quality. These include using tools that collect longitudinal data, as well as more closely integrating participants into the research protocol (Dema et al., 2019). Further, Ferster et al. and Heiss and Matthews both note that data quality can be improved through suitable training for volunteers and through focusing on particular areas (Ferster et al., 2013; Heiss and Matthes, 2017). Finally, Drosatos et al. note that privacy enhancing technologies for preserving participant confidentiality may necessitate compromising on data quality (Drosatos et al., 2014).

Intellectual Property, Data Rights and Confidential Information

Intellectual property and data ownership may refer to a number of overlapping rights. Each of these rights may apply to different aspects of citizen science research driven by Internet of Things devices. First, a prevailing ethos in citizen science research is the importance of open science (Wiggins and He, 2016; Weir et al., 2019). This principle requires open access to and licensing of publications, methodologies, tools, software, research guidelines, and data (Wylie et al., 2014; Theunis et al., 2017; Yu et al., 2017; Komninos, 2019; Harlow et al., 2020; Pejovic and Skarlatidou, 2020). In particular, Komninos reports that ensuring data was made openly available was an incentive for citizen scientists to participate in the project (Komninos, 2019). Further, a number of the studies included in this sample described the benefits of using low cost open access technologies for ubiquitous research (Black and White, 2016; Carton and Ache, 2017).

However, the presence of intellectual property and moral rights over data can impact whether data is made openly available. Further, the lack of guidance in this area can present a challenge for researchers planning to use both open data and open source technology. Often, these issues must be resolved on a case by case basis. For example, Wylie et al. describe how a collective for environmental citizen science encouraged the hosting research institute to update their policies on licensing for open source technology (Wylie et al., 2014). Verma et al. report on how the ownership of data and images about wildlife could not be transferred across borders due to the potential of identifying endangered species (Verma et al., 2016). Conversely, the absence of intellectual property or rules governing sharing can also have an impact on open access to data, Yu et al. note that the ethics of crowdsourcing big data from farmers as part of agricultural research may depend on who is collecting this data. In particular, industrial agricultural businesses such as Monsanto may gain a significant informational advantage over farmers if they freely benefit from such open research (Yu et al., 2017). Guaranteeing privacy for participants and ensuring data quality, particularly for the reproducibility of research, represent two further competing considerations militating against the use of open data without licensing requirements (Drosatos et al., 2014; Denefleh et al., 2019).

An incidental finding to the identification of ethical issues that indirectly relates to intellectual property concerns the type of devices used for research purposes. The most frequently used terms to describe tools for citizen science projects were smartphone (n = 27), sensor (n = 22) and wearable (n = 13). Less than a third of the results included in this scoping review refer to "Internet of Things" (n = 10) as the class of devices used in their research. By contrast, the use of terms associated with customisable devices ("Internet Connected", "Connected Devices", "Ubiquitous Computing" and "Pervasive Computing") is relatively low.

PART 3: DISCUSSION

This scoping review has identified the occurrence of the three overarching categories of ethical issues mentioned in current literature; privacy, data quality, and intellectual property. Accordingly, this section will discuss the legal and ethical factors raised by these issues. Moreover, recommendations will be offered on how to construct citizen science projects involving Internet of Things devices that address potential challenges in this regard.

First, the preceding analysis reveals that a number of ethical considerations must be integrated into the project design in a very early stage. Notably, all citizen science projects should have a protocol that adequately protects participant autonomy and privacy. A number of existing theoretical and case study derived frameworks have defined privacy protocols for Internet of Things devices in citizen science research projects (Rothstein et al., 2015; Evans, 2020). These frameworks focus on specific ethical and legal issues that may arise from using Internet of Things devices in citizen science projects, including how citizen science projects can comply with privacy legislation in particular jurisdictions. However, the authors of these frameworks note that privacy legislation may not apply to all citizen science projects. For example, these frameworks use the Health Insurance Portability and Accountability Act (HIPAA) from the United States as a reference point for privacy law. Nevertheless, HIPAA only applies to personal health information shared by healthcare providers or health insurers, and manufacturers of Internet of Things devices may not be required to necessarily comply with HIPAA.

Although privacy, like intellectual property, are regulated by specific legislation, and have been addressed in other ethical frameworks, these issues are contextually dependent (Cooper et al., 2019). Specifically, the scientific research team should consider whether personal data is being processed as part of the project. In particular, the analysis of many citizen science projects revealed a nebulous distinction between what Internet of Things devices that do and do not process personal data. The scientific research team should also consider whether participants may potentially submit sensitive personal data, or whether these data can be inferred about participants. Likewise, whether data has been truly anonymized, or could still be considered personally identifying information, depends on both the data and the environment it has been released into. The scientific research team should ensure data privacy by design, and that the Internet of Things devices used by participants are both privacy-enhancing and secure. This security is particularly important in the context of commercially offered smartphones and wearable devices, where the users may not have control over privacy settings. To this end, a commons of resources for ethics with respect to Internet of Things based citizen science research projects and adequate processes of oversight can be crucial for conducting contextually appropriate studies (Harlow et al., 2020; Jobin et al., 2020).

Another issue that was only briefly addressed in some of our results was the question of differences in privacy law between jurisdictions. In particular, the recent European Union General Data Protection Regulation (GDPR) grants data subjects a number of rights over their personal data. One of these rights is the right to data portability, or the ability to have machine readable data transferred from one device to another. Article 20 applies to data that has been submitted by an individual subject to data subject consent or a contract, and accordingly has a relatively limited operation. Despite the relatively limited circumstances in which it applies, this right may have a direct impact on citizen science with Internet of Things devices (Quinn, 2018). Therefore, researchers should integrate strategies to deal with these concerns in their study protocol.

This review also identifies ethical issues that may sit outside the realm of a specific field of legislative regulation. The lack of regulation for citizen science projects include potential trade-offs between privacy, data quality and open access to data. The ethical issues surrounding data quality are also dependent on the study design, the discipline and devices in question. To resolve data quality issues as part of citizen science research, researchers must consider a number of factors contextually. Specifically, it is necessary to consider the types of data that are being collected and in what context. For certain types of data such as visual data of wildlife, the accuracy of data might be less important than the portability of devices (Verma et al., 2016; Dema et al., 2019). To this end, it is important to customize or design Internet of Things data collection devices that are appropriate for the environment in which they are used. Pejovic and Skarlatidou observe how a number of citizen science projects involving indigenous populations in regional areas required supplying low cost devices for these communities suited for regional research (Pejovic and Skarlatidou, 2020). Likewise, Younis et al. describe how for near field communication (NFC) devices, positioning is vital to ensure the accurate collection of data (Younis et al., 2019).

It is also necessary to consider alternative strategies to raise data quality and representativeness, as well as reduce bias. In particular, algorithmic strategies to reduce bias may include assigning rewards for less popular or more spatially distributed tasks (Acer et al., 2019). Outside of technical strategies, it may be possible to also crowdsource validating data. This process would involve recruiting a separate set of participants whose task it is to guarantee the validity of data collected by another set of participants (Wiggins and He, 2016). Nevertheless, any strategy to reduce bias should be employed contextually, recognizing in some cases respondent bias can offer valuable insights by itself (Havinga et al., 2020). In particular, the studies included in this scoping review demonstrate how Internet of Things devices can help citizen scientists play a more active and personally enriching role than they otherwise would as research subjects. Further, the fact that citizen scientists might have strong personal motivations to participate in research might strengthen the importance of that research. Actively participating research subjects can help generate new forms of social innovation from research through peer production of knowledge (Schäfer and Kieslinger, 2016; Peters and Besley, 2019).

A final issue that is not addressed by any of the studies included are the legal rights that Internet of Things device developers hold (Montori et al., 2018). This issue is related to the types of devices used for research purposes, as defined by the use of terms above. There are a number of possibilities to explain this finding. A first hypothesis is that terms such as "Internet of Things", "Ubiquitous Computing" and "Pervasive

Computing" are academic terms and are not used in a technical context to describe the tools being used. A second one is an inconsistent use of terms across disciplines (Crampton et al., 2016). The third possible explanation is that citizen science research in our sample largely involves smartphones and wearables sold by manufacturers with proprietary clouds, otherwise known as "the intranet of things" (Montori et al., 2018). This third hypothesis is supported by the fact that the majority of the studies ($n = 27$) included in this scoping review used either apps relying on smartphone sensors or commercially available devices. By contrast, only a minority of studies used custom designed devices, or devices built using microcontrollers such as Raspberry Pi or Arduino circuit boards (Wylie et al., 2014; Black and White, 2016; Verma et al., 2016; Tironi and Valderrama, 2017; Barzyk et al., 2018; Dema et al., 2019; Denefleh et al., 2019).

These commercial devices can be contrasted with custom manufactured open source platforms, which users may require more time to become familiar with (Black and White, 2016; Denefleh et al., 2019). In particular, Theunis et al. note that no device can be used for pervasive effortless data collection due to cost or inherent quality issues (Theunis et al., 2017). Therefore, the use of commercial devices may represent an appropriate compromise between each of these factors. Nevertheless, proprietary Internet of Things and mobile devices may have security vulnerabilities that may not be revealed to the project team (Montori et al., 2018). These vulnerabilities raise specific privacy concerns for data collectors, as well as concerns about the verifiability of any data collected using these platforms (Schmitz et al., 2018). Further, commercial smartphone and wearable developers may have their own intellectual property rights over data uploaded to their platforms. Therefore, it cannot be assumed that all open data (including anonymized data) is prima facie ethical to share and reuse. Instead, the decision to use commercial or open source hardware, as well as any intellectual property concerns, should be determined on a case by case basis.

CONCLUSION

The increased prominence of citizen science projects has coincided with a proliferation in the number of Internet of Things devices. The portable, low cost and connected nature of these devices has made them ideal for carrying out citizen science research, fostering social innovation. However, the use of these devices also may raise ethical and legal issues. To identify these issues, this scoping review contains an analysis of 34 studies from a variety of fields that employed a variety of different citizen science study designs. Privacy, data quality and intellectual property related concerns were identified as the three main issues communicated by researchers. Building on an analysis of these ethical issues with regard to ethical, legal and social implications, this article identifies recommendations for researchers on how they could ethically integrate participants into citizen science research projects. First, researchers should develop a specific protocol for how to ensure both adequate consent and data protection for non-institutional scientific researchers. This protocol should also allow individuals to exercise their rights under data protection or privacy laws (depending on the jurisdiction). Secondly, researchers should consider the types of data that are being collected using citizen science devices, and what the quality requirements for that data are. Thirdly, where possible researchers should consider how intellectual property rights will be handled, and whether these rights might influence the choice of device. Overall, this analysis of these issues contributes to inform future work on specific ethical issues in citizen science research using Internet of Things devices.

AUTHOR CONTRIBUTIONS

JS, AJ, and EV contributed to conception of the study. JS and AJ designed and tested the protocol. JS performed the analysis and wrote the first draft of the manuscript. AJ contributed sections to the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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