Minerva (2024) 62:549–572
https://doi.org/10.1007/s11024-024-09529-z

Mapping Approaches to 'Citizen Science' and 'Community Science' and Everything In-between: The Evolution of New Epistemic Territory?

Nick Hacking[1,2] · **Jamie Lewis**[1,2] · **Robert Evans**[1,2]

Accepted: 3 April 2024 / Published online: 22 May 2024

Abstract Over the last decade or so, the rate of growth of academic publications involving discussion of 'citizen science' and 'community science', and similar variants, has risen exponentially. These fluid terms, with no fixed definition, cover a continuum of public participation within a range of scientific activities. It is, therefore, apposite and timely to examine the evolving typologies of citizen science and community science and to ask how particular disciplinary actors are shaping content and usage. Do certain approaches to citizen science and community science activity remain siloed within specific disciplines or do some approaches resonate more widely? In this study, we use mixed methods—bibliometric and textual analysis—to chart the changing academic interpretations of this scientific activity over time. We then ask what these analyses mean for the future direction of academic research into citizen science and community science. The results suggest that, while certain disciplinary-based interpretations have been particularly influential in the past, a more epistemically mixed array of academic interests than was previously evident

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11024-024-09529-z.

✉ Nick Hacking
hackingn@cardiff.ac.uk

Jamie Lewis
lewisjt1@cardiff.ac.uk

Robert Evans
evansrj1@cardiff.ac.uk

1 Wales Institute of Social and Economic Research and Data (WISERD), Cardiff University, Spark | Sbarc Building, Maindy Road, Cardiff CF24 4HQ, Wales, UK

2 School of Social Sciences (SOCSI), Cardiff University, Glamorgan Building, King Edward VII Drive, Cardiff CF10 3WT, Wales, UK

are currently determining expectations of what citizen science and community science should look like and what they can be expected to deliver.

Keywords Citizen science · Community science · Science and technology studies · Bibliometric analysis · Sociology of knowledge · Power relations

Introduction

The rate of growth of academic publications involving discussion of 'citizen science' and 'community science' has risen significantly since 2010. Alongside this, several papers have been published that categorise the different projects to which these labels have been attached. This literature proposes a variety of different typologies of citizen science based on, for example, the extent to which citizen scientists are (or are not) able to influence things like research questions and design, data collection instruments and/or the analysis of results (including, but not limited to, Wiggins and Crowston 2012; Haklay 2013; Shirk et al. 2012; Prainsack 2016; Den Broeder et al. 2018; Strasser et al. 2019). In summary, the term 'citizen science' is often associated with more top-down, science-led projects that provide citizen scientists with clear roles and directions, while the term 'community science' typically refers to more bottom-up projects with a stronger emphasis on co-production and collaboration at all stages of the research process.

In this paper, we are also concerned with the theory and practice of citizen science but ask whether the different forms and approaches found in the literature reflect and represent coherent disciplinary approaches to such work. For example, it is well known that citizen science approaches have become popular in disciplines such as Ecology, Hydrology, Archaeology, Sustainability, Medicine, Meteorology and Astronomy (Bautista-Puig et al. 2019; Strasser et al. 2019; Heigl et al. 2019), but what we are interested in exploring is whether there is a common definition or practice that is shared across some or all of these different disciplines or, if instead, there are discipline-specific variants at work. If there is evidence of the former, this would suggest citizen science is becoming a discipline in its own right. If not, the implication is that different versions of citizen science exist, embedded within and influenced by the epistemic cultures of their 'host' disciplines. Finally, the situation is unlikely to be static, so we are also interested in examining how claims to citizen science circulate and what this can tell us about the likely direction of citizen science research, either as a mosaic of disciplinary variants or, possibly, as an emergent, coherent discipline (Pettibone et al. 2017; Tauginienė et al. 2020).

We approach these questions via a bibliometric analysis that examines the frequency with which 'citizen science' and 'community science' appear in the literature, the citation networks that exist between these publications, and the disciplinary affiliations of the authorship teams that use them. In this way, we use networks of scientific documents to explore both the emergence of new research fronts (Leydesdorff and Amsterdamska 1990; Van den Besselaar and Leydesdorff 1996; Leydesdorff and Schank 2008; Leydesdorff et al. 2018; Leydesdorff and

Etzkowitz 1996) and the links between research groups or disciplines (Crane 1972; Davidson Frame and Carpenter 1979; Chubin et al. 1986). In doing so, we delineate the epistemic territories linked to the practices labelled citizen and/or community science. We define mapping epistemic territory as finding out about the nature of new knowledge and how that knowledge is attributed. In line with Knorr Cetina (1999), we recognise that there is a pluralism with different epistemic cultures which employ a range of methods and tools to arrive at scientific knowledge. Over time, in an institutional and evolutionary fashion, we expect some knowledge to establish its own unique and resilient epistemic qualities, whilst other knowledge will not.

In what follows, we first summarise the existing typologies of citizen science and community science, setting out in more detail the range of different ways in which they are being conceptualised and/or practiced. Through a review of typologies in the next section, as well as with our own results and analysis in the fourth section, we suggest that there is a broad, binary division in terms of claims to knowledge that is captured in the distinction between 'top-down' versus a 'bottom-up' approaches introduced above. The third section explains the methodology and methods used for this study. Conclusions and a future research agenda are presented in the final section.

Citizen Science and Community Science: Typologies and Approaches

In the 1990s, there were two independent pieces of research that coined the term *citizen science*, but which did so in very different ways based, in no small part, on their disciplinary and geographical origins. These broad divisions still inform debates today and largely accounts for the diverse and sometimes contradictory practices now grouped under this umbrella term (Cooper and Lewenstein 2016; Strasser et al. 2019).

One approach is exemplified by Science and Technology Studies (STS) scholar Alan Irwin. In a period when European countries were experiencing very specific environmental and health crises, such as the nuclear catastrophe at Chernobyl, the development of genetically modified organisms (GMOs), and the outbreak of 'Mad Cow Disease', Irwin defines citizen science as science *by* the people and *for* the people. Irwin regards citizens as potential epistemic agents, acting from the *bottom up*, and in a potentially adversarial relationship with more traditional forms of expertise. Irwin's approach thus sees citizen science as a normative attempt to re-balance asymmetric power relations between actors. For citizen science to advance in this interpretation, relatively 'powerless' individuals, e.g., in a land use planning dispute, link together with others within localised communities to gather data that can be used as evidence to challenge the mainstream science used by more powerful institutions to inform or justify decisions (Strasser et al. 2019). In recent years, social scientists have begun to refer to this approach to citizen-based research *community science* (Dosemagen and Parker 2019).

The alternative definition of citizen science is typically associated with Rick Bonney, formerly at the Ornithology Lab at Cornell University, whose paper *Citizen science: A lab tradition* (1996) defines citizen science as a *top-down* science-led enterprise that seeks "amateur-collected data in an organized fashion" (Bonney 1996: 7) and which builds on traditions developed within the natural sciences during the early 19th century.[1] In this model of citizen science, concerned citizens act as volunteers and contribute to the scientific endeavours of a sponsor such as a university by collecting data that would otherwise be unavailable and, in return, they:

> [develop] skills, … imbibe the process of scientific investigation, and gain the satisfaction of furthering scientific knowledge (p. 7).

Subsequent research suggests that, while boundaries between volunteers and scientists are not always clear in practice, control of *citizen science* investigations, chiefly in terms of research design and analysis, is retained by scientists at the sponsoring research institution (Kasperowski and Hillman 2018: 585).

It is also worth noting that the North American social, cultural and political context of the development of the term *citizen science* is somewhat different to that of Europe (Eitzel et al. 2017). Headlines about environmental crises in the 1980s and 1990s were typically well amplified in Europe to already potentially greater levels of awareness of pollution and green politics at regional, national and international levels. However, the often intensely local dimension of a similarly wide range of US pollution scares does not necessarily reduce the amplification of such issues in US local media (and hence in local politics). In the 1980s and 1990s, the term 'popular epidemiology' was being used by sociologists based in the US (e.g., Brown 1987, 1992, 1993) and it became closely related to citizen science (Brown 1997) not least in the case of AIDS activism (Epstein 1996). Similar polluting concerns to Europe existed in the US, e.g., with the Love Canal disaster in New York State in the 1970s which was echoed more locally with leukaemia from chromium polluted land (Brown 1997) and the work of the 'Louisiana Bucket brigade' in identifying poor air quality near to oil and gas plants (from 2000) (Ottinger 2010). These different hinterlands are important as they influence current funding arrangements. Funds for research activities are largely mediated by the Association for the Advancement of Participatory Sciences in the US (significantly changing its title from the 'Citizen Science Association' in early 2023) and the European Citizen Science Association, respectively. As such, the members of these key scientific associations are currently moving in slightly different directions based upon internal debates over the efficacy of the term *citizen science* to attract funding (for example from the European Research Council) and to establish the nature of this epistemic territory.

This growth of research in this area has thus led to several different typologies of the field that map and characterise its practices across a variety of different dimensions. In what follows, we review and categorise the leading typologies, setting out their key features but also linking them back to the core distinction between top-down and bottom-up approaches. The aim of this analysis is to explore the extent to

[1] Crowdsourcing of ornithological data via volunteers became more formalized in 1965 through the efforts of researchers at Cornell with their 'Nest Record Program'.

Table 1 Citizen science and community science typologies

Typology type	Categories/dimensions	References
1. Numbers of participants versus resources	Scale (local or mass) versus thoroughness (resource investment)	Roy et al. (2012)
2. Degrees of public participation (power relations)	Community consulting, community-defined research, community workers, and community-based participatory research	Wilderman (2007)
	Contributory (led by experts), collaborative, or co-created	Bonney et al. (2009); Stevens et al. (2014)
	Level 1: crowd sourcing Level 2: distributed intelligence Level 3; participatory science Level 4: extreme citizen science (or collaborative science)	Haklay (2013)
	Contributory (led by experts), community-led, or co-created	King et al. (2016)
3. Goals-based	Aims linked to organizational/institutional characteristics including divisions between experts and non-experts	Wiggins and Crowston (2011, 2012)
4. Hybrid	Coordination, participation, community, evaluation, openness, entrepreneurship	Prainsack (2016)
	Aims, approaches, scale (local or mass)	Den Broeder et al. (2018)
	Sensing, computing, analysing, self-reporting, making	Strasser et al. (2019)

which differences between approaches are informed by the broad disciplinary divisions into which they fall.

Table 1 summarises the review and identifies the four leading types of typologies used in classifying citizen science and community science activity:

1. numbers of participants versus resources,
2. degrees of public participation,
3. goals-based, and
4. hybrid approaches.

The first group turns on the number and spread of different types of participants. Roy et al. (2012: 5), largely from the Natural Environment Research Council's (NERC) Centre for Ecology and Hydrology in the UK, follow Bonney in defining citizen science as "the involvement of volunteers in science". Their analysis of 234 case studies produces two main axes: the degree of mass participation and the thoroughness of investigation (i.e., the total amount of resources used). This gives a four-cluster classification of: (1) simple local projects, (2) thorough local projects, (3) simple mass participation projects, and (4) thorough mass participation projects.

Stressing the enabling of citizen science activity via the internet, one of Roy et al.'s (2012: (8) key claims is that this top-down approach provides a way of aligning citizen science with pre-existing scientific and policy goals:

> Citizen science has vital roles in scientific research and engagement/ education, but it also has the potential to help meet the demands of environmental/ biodiversity monitoring, giving it a clear relevance to policy.

The second typology in Table 1 stresses the different degrees of community control over a project, with Wilderman (2007: 9–10, 12), a Professor of Environmental Science, preferring to use the term 'Participatory Action Research' or (PAR) for what others would call community science. Two other examples of this type come from interdisciplinary teams (mixing Computer Science, Anthropology and Geography): Haklay (2013) and Stevens et al. (2014).[2] Haklay's (2013) four level typology of participation reflects Bonney's general approach, with only 'Level 4'—"Extreme Citizen Science (or Collaborative Science)"—coming close to Irwin's more bottom-up definition. Even here, however, community members do not necessarily co-produce knowledge and collaboration may be limited to *how* to tackle local concerns (cf. Cornwell and Campbell 2012). In a similar vein, Stevens et al. (2014: 20) write that:

> Participatory citizen science shows potential in promoting long-term, sustainable management of key world environments and supporting the rights of those living in such environments by empowering citizens to collect, interpret, and use scientific information in a way that's useful for them.

[2] Both were funded by the UK's Engineering and Physical Sciences Research Council.

Finally, in the same group, medical researchers King et al. (2016: 4) define citizen science in a broadly top-down way: "[citizen science involves] members of the public who work with professional scientists to advance a research project." This activity is divided up into:

1. citizen science "for the people" involving voluntary donations of time, data and other activities to advance a research field, and
2. citizen science "with the people" where community members help with observational data collection (King et al. 2016).

Both of these modes of activity are like Bonney's natural sciences' approach, although a more activist 'Community-led' model leading to co-created knowledge is also mentioned. More recent work on participation-based typologies has seen a focus on barriers—see, for example, Allen (2018) and Benyei et al. (2021)—both authors have social science hinterlands.

The third kind of typology surfaced when Wiggins and Crowston (2012), both Information Science researchers, examined previous citizen science case studies. They found that: "[Public participation], while intuitive and straightforward, *does not highlight conceptually interesting relationships*" (Wiggins and Crowston 2012: 3432, emphasis added) suggesting that there is no relationship between participation and any other variable. Instead, they argue that citizen and community science projects are more usefully categorised by the tasks participants perform and the goals their project seeks to achieve.

The fourth typology involves a combination of elements from the other three groups plus a focus on power and process. Prainsack (2016), an STS scholar, proposes a six-category schema where the assessment of a project's success depends upon the main unit of analysis. This can be the degree of democratisation of science, the education of citizens or solving a pressing scientific issue in a way. The degree of democratisation is particularly interesting as it spans top-down and bottom-up approaches, with Prainsack suggesting that:

> [Citizen science] represents a significant change in how we assess and enact relevant *expertise and authority* when we create scientific knowledge, and how it does or should affect the ways in which we discuss and support participation in science (Prainsack 2016: 20, emphasis added)

Also, in the hybrid group are Den Broeder et al. (2018), who are Health researchers. They exclude the 'thoroughness' characteristic of Roy et al. (2012) and mix goals with participation levels to produce a multi-dimensional approach that forms: "a basis for studying, comparing and exploring the opportunities and limitations of public health Citizen Science". In this sense, and despite the differences in approach, they occupy a similar position to Roy et al. (2012) in that the contribution to policy is foregrounded.

Finally, in the last example of the hybrid typologies, Strasser et al. (2019), who are social scientists, base their typology on five *epistemic* practices—sensing, computing, analysing, self-reporting, and making—that look "beyond the recent initiatives carrying the label ‘citizen science’ and capture the greater diversity of participatory practices” (Strasser et al. 2019: 55–56). In this way, they echo the claims made by Prainsack about the potential for citizen science to carve out new epistemic territory and override existing participatory classifications.

In summary, elements of both the top-down, natural science-based approach to citizen science and the more bottom-up, social science-based approach to community science are in evidence within the typologies in Table 1. The typologies reveal these contrasting framings of scientific activity as different allocations of power and control between the sponsoring scientists and the citizen/community volunteers (cf. Arnstein 1969; Callon et al. 2009). Advocates of citizen science from natural science disciplines see citizen science as furthering existing research agendas and enabling them to remain policy relevant. By contrast, social science-based approaches see the creation of local knowledge transforming project participants from ’workers’ into community-based ‘scientists’ who can, and should, exert greater control over a project’s research design and analysis.

Methodology and Methods

The use of bibliometric data is widespread in the natural and social sciences. According to Andrés (2009: 1), researchers should “choose an analysis … according to the characteristics of their own research field.” The only norms for bibliometric studies are process-oriented: (1) defining the kind of data to be assessed, (2) defining the data fields used, and (3) doing a bibliographic search that ensures unbiased, consistent, and accurate coverage, and which is fully explained (to allow for replication) (Andrés 2009; Ninkov et al. 2021).

As we are interested in the emergence of a new sub-field in the academic literature, we included a mixture of descriptive analysis (e.g. the annual number of outputs) and relational analysis which identifies the relationships between peer-reviewed outputs and their authors (e.g. the ‘betweenness’ of published works and the degree of interdisciplinarity). Also, when highly cited documents are analysed longitudinally, they can reveal structural changes over time in this potentially emergent episteme, or area of knowledge and understanding. Key publications were therefore identified and subjected to a more detailed, qualitative analysis. These aims can be summarised by three research questions, which, in turn, imply the data and methods needed to provide their answers.

1. How can the changing disciplinary nature of academic outputs in this field be characterised over time? This involves identifying the following indicators about output numbers and relative influence:

    (1a) Annual/cumulative publication production, 1995–2021;
    (1b) Annual percentage shares of leading research areas, 1995–2021; and

(1c) Leading authors/publications/journals in terms of total citations (cumulative to 2021).

2. How multidisciplinary are the authorship teams of publications using the terms 'citizen science' or 'community science' and has this changed over time. This was addressed with two indicators (cf. Raasch et al. 2013):

   (2a) Mapping of cumulative co-authorship patterns of citizen science and community science publications, 1995–2021; and
   (2b) Discipline assortativity (*r*) from co-citation proximity analysis. *r* varies with the shape of the overall network each year from 1995 to 2021 from 1.0 to − 1.0. 1.0 indicates a completely homogeneous body of knowledge. − 1.0 suggests it is completely heterogenous (Raasch et al. 2013).

3. How are the terms 'citizen science' and 'community science' being used in relation to disciplinary traditions? This requires an assessment of authors' use of the terms, which was undertaken through a qualitative content analysis of twelve highly cited publications from different disciplines reflecting their share of all publications for 2021.

Central to this activity was the creation of a bibliometric database. Two online databases of academic outputs, Scopus and Web of Science, were searched in May 2022 using the terms "citizen science" and "community science".[3] As our interest is when these specific terms were first used and then taken up by others, these terms rather than broader searches, such as "citizen scien* or community scien*", were used. The data range begins in 1995, reflecting Irwin's original publication, and ends in 2021.[4] Searching both Web of Science and Scopus offered the broadest and most accurate coverage. Google Scholar was not searched.[5] A combined and weeded list of publications was created in Microsoft Excel using the 'VLOOKUP' function to identify, match and delete duplicate entries and publications' unique digital object identifiers (DOIs). The resulting database contains 6282 peer reviewed publications.

We note that indicators linked to citations need to be used cautiously as they can be contested in terms of representing quality. This is the case not least because citations can be used reputationally in a negative as well as positive way (Leydesdorff and Amsterdamska 1990). Likewise, although each publication's disciplinary research areas were included in the database, these categorisations are always up for debate. As Jonsen (2004: 32–3) suggests of disciplinarity in the modern university era:

[3] The Scopus and Web of Science searches were both in 'Documents' and 'All fields'.

[4] Irwin (1995) and Bonney (1996) were not available in either database because of more limited Scopus and Web of Science coverage pre-1997. Information for these publications was added manually.

[5] For concerns about *Google Scholar*'s comprehensiveness and accuracy, see Meho and Yang (2006) and Adriaanse and Rensleigh (2013).

> the clear lines of many classical disciplines have diffused into mosaics: even the most definitive ones, such as mathematics and physics, are complex collections of sub-disciplines with quite diverse theories, methods and even definitions of the field. […] The lines between the new and the old blur and methodologies proliferate.

Where publications had more than one disciplinary area, a fractional weighting system was used. These results, when aggregated and displayed as annual percentage shares for all publications, are at least suggestive of some degree of influence.

With the new database, the references list for each publication entry was occasionally longer than the individual spreadsheet cell limit in Excel, resulting in some truncation of publications' reference data (estimated to have affected ~ 30 files of the 6282 publications, or 0.005% of the total). Other errors and inconsistencies, spelling mistakes, and non-uniform abbreviation formats were also corrected by hand. Citation, co-citation and co-authorship visualisations and data tabulations were then produced by importing the data into the VOSviewer social network analysis software.

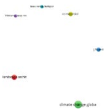
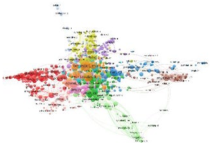
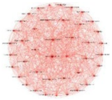
Collaboration can be defined as working with others in an intellectual endeavour (Shrum et al. 2007). In this study, vector maps produced in VOSviewer software and based on bibliometric data—co-citation analysis—reveal linkage in social networks between clusters of documents, authors, and co-authors. The smaller the distance between things on vector maps, the stronger the network relation (Wasserman and Faust 1994; Faust 1997; Knoke and Yang 2008). This analysis shows the input of different scientific specialties in a new area of knowledge (Small 1973; Börner et al. 2003; Boyack et al. 2005; De Moya-Anegón et al. 2007).

Author co-citation analysis (ACA) is used to reveal the changing betweenness, or centrality, of citations to the work of thousands of academic authors. On a vector map, ACA reveals the frequency with which two items of prior literature by particular authors are cited together by an author in later literature (Small 1973). Using VOSviewer software with cumulative annual data, ACA identifies which authors (and their leading publications) are considered central to the framing of 'citizen science' and 'community science' in successive years.[6]

From this data, twelve publications were selected for qualitative analysis in order to identify the way in which highly cited papers construct and define citizen science or community science activities (Appendix A, supplementary material). The criteria used were: (1) language, (2) the broad approach chiefly in terms of who controls the design and analysis, (3) any claims to knowledge/utility, (4) which resources are thought to enable things to happen, and (5) the authors' characterisations of the nature of expertise in evidence. To minimise the risk of any misjudgement at the beginning of the process, each co-author assessed four different papers, and then compared each one against one another (Appendix B, suppl. material). Consensus with these assessments was then sought between us. This process enabled

[6] Different versions of individual author's names in the Web of Science/Scopus data were standardised prior to VOSviewer's analysis.

Table 2 Typology of network clustering

Cluster type	Sample shape	Description
(a) Chain- or ring-shaped		(1) A string of co-citations with no significant cross-links (2) Each group of three may share a common issue (3) Outermost references of the chain may show little overlap (4) Can scarcely be interpreted as a community
(b) Star-shaped		(1) A single, often cited reference dominates (2) Several other references are grouped around (1) (3) References from (2) show little inter connection (4) Community is grouped around one or two historic documents (5) Satellites represent part aspects of research area
(c) Complete		(1) Each reference is connected to another (2) No dominant document (3) Indicates the formation of a school of research

differences in interpretation to be identified and the reasons for such differences to be discussed.

Finally, we examined how collaborations, as represented by citation patterns, have changed over time. Mapped items are usually distributed unevenly as clusters of related authors/documents. According to Gmür (2003: 32), clusters can be considered to be 'self-contained communities' if they have: (1) at least one fully interconnected group covering three references, or (2) a group of five references with star-shaped connections. Cluster interpretations are summarised in Table 2. The first is the (a) *chain- or ring-shaped cluster* where a number of unconnected disciplinary clusters fail to form a community. A second type is (b) *star-shaped* where a single, oft-cited reference dominates, but satellite activity creates points of a star. Finally, a third cluster type, (c) *complete*, is where each reference is connected to each another and none dominates. This pattern suggests the formation of a new school of research (Gmür 2003). The identification of clusters in VOSviewer occurs via an inductive process based upon analyses of similarities. Annual snapshot images from VOSviewer were then produced.

The tendency for the entire network of authors and their publications to link together as clusters was also checked using a measure known as discipline assortativity (r). Assortativity is the degree to which the overall network—here noted for each year from 1995 to 2021—is clustered around similar disciplinary references (i.e., high assortativity would be reflective of Gmur's *complete* pattern in Table 2). Pajek software, used for social network analysis, was deployed to see if r gave a figure approaching 1 for complete assortativity or whether network connectivity was closer to -1 which indicates complete disassortativity, i.e. where little or no clustering patterns exist (cf. Raasch et al. 2013).

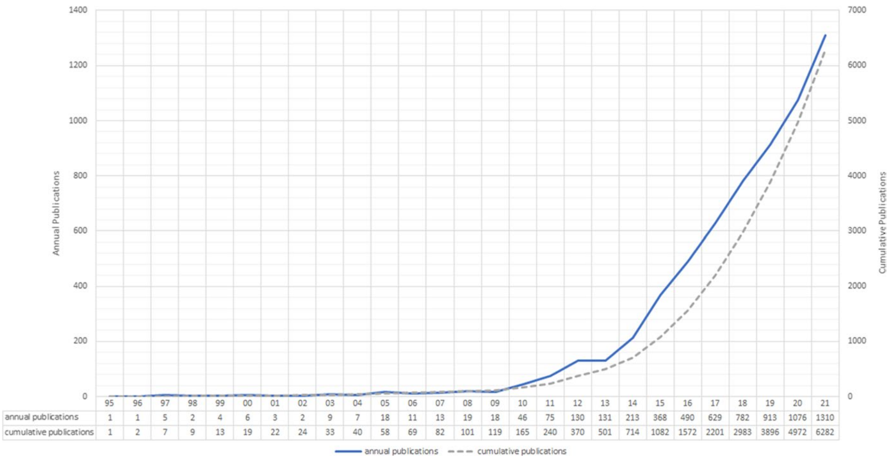


Fig. 1 Annual and cumulative totals of publications, 1995–2021. *Source*: Web of Science/Scopus, 7.5.22

Results and Analysis

The disciplinary patterns of academic research into citizen science and community science as they have developed between 1995 and 2021 are reported here.

With the bibliometric analysis, Fig. 1 combines annual and cumulative total numbers of publications (Indicator 1a). This graph reveals the rapid expansion of the citizen science field since 2009/10. Strasser et al. (2019) have highlighted some key events which have impacted on publication rates. In 2006, scientists at the University of California's Berkeley Space Sciences Laboratory, for example, created a web platform, Stardust@home, where volunteers could operate a virtual microscope to identify rare interstellar particles from online images. This was followed by Galaxy Zoo (2006) which analyses the shape of galaxies, the Foldit project (2008) where people could fold proteins in three-dimensions, and Penguin Watch (2014) which counted the inhabitants of large colonies. A Zooniverse web platform hosting such citizen science projects was then launched by Chris Lintott and Kevin Schawinski, astrophysicists at the University of Oxford, in 2009. This activity was followed with the founding of the US Citizen Science Association, which held its first conference in 2012. The European Citizen Science conference began in 2016, with similar academic activities multiplying rapidly since then, all of which has fed into the ever-rising production of publications shown in Fig. 1.

In terms of disciplinary locations, the cumulative publication numbers up to 2021 (Appendix C, suppl. material) show that nine of the top twenty most influential journals (based on the numbers of publications) with citizen science and community science articles are biology-based. Appendix D (suppl. material) further reinforces this picture of disciplinary dominance by revealing that seventeen of the top twenty most cited authors' articles have been published in biology-based journals.

That said, there is also evidence that the dominance of biology is in decline, at least as measured by relative percentage share of publications (Fig. 2). In recent years, growth domains and disciplines include Geography and Sustainability,

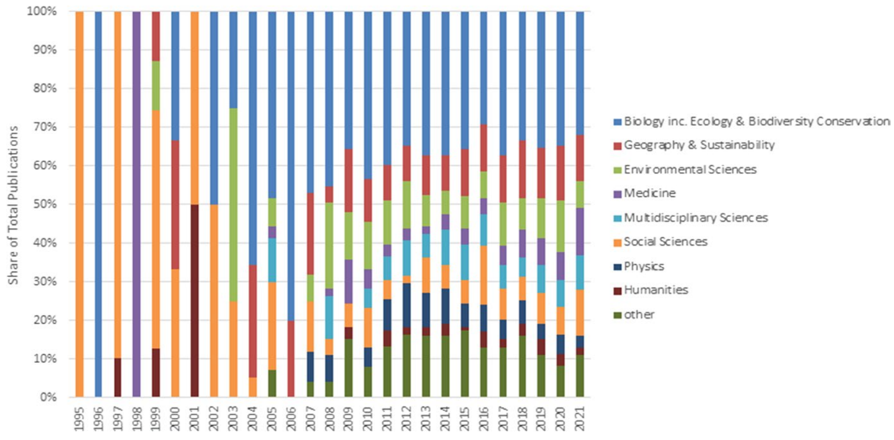


Fig. 2 Percentage share of research areas, 1995–2021. *Source*: Web of Science/Scopus, 7.5.22; percentage data in Appendix E

Environmental Sciences and Multidisciplinary Sciences. Figure 2 provides an annual percentage share of aggregated research areas for all publications between 1995 and 2021 (Indicator 1b). With low publication numbers early on, no particular research area dominates consistently until 2004 where 'Biology inc. Ecology and Biodiversity Conservation' accounts for 63% of the total (Appendix E). Apart from a jump in 2006 to 80% of total publications, this figure progressively declines to a 32% share in 2021. This decline has made way for 'Geography and Sustainability' which first appeared in 1999 and is fifth-equal placed in 2021 with a share of 12% of all publications. Similarly, the seventh ranked research area in 2021 is 'Environmental Sciences', which also first appeared in 1999, had a 7% share in 2021.

Medicine, which first appeared in 1998, maintains a relatively small share of publications from then until 2021. Social Sciences which started with Irwin (1995), since 2007 has varied between a 2% and 15% share before reaching 12% in 2021. Physics, specifically Astrophysics, is a late starter, first appearing in Fig. 2 in 2007 with interest in the Galaxy Zoo project. This figure rises between 2010 and 2014, but then drops back to just a 3% share in 2021. 'Humanities' have a steady presence from 2007 at around 1–3%, while the 'Other' category has declined progressively from 2012 as authors' outputs in other categories appear to have consolidated their relative shares.

Taking Fig. 2 as a whole, our interpretation is that, after some initial variation, the disciplinary areas where publications relating to citizen science and community science come from have been relatively stable since around 2007.

But what of interdisciplinarity? The publications database permits analysis of interdisciplinarity via co-authorship patterns (cf. Raasch et al. 2013). In the early stages of a co-authorship network, interdisciplinary dyads, triples, quads and quintuples are prominent. This is because, early on, genuine cross-fertilizations of ideas about problem solving tend to dominate (Raasch et al. 2013). Figure 3 shows the cumulative co-authorship network for citizen science publications from 1995 to

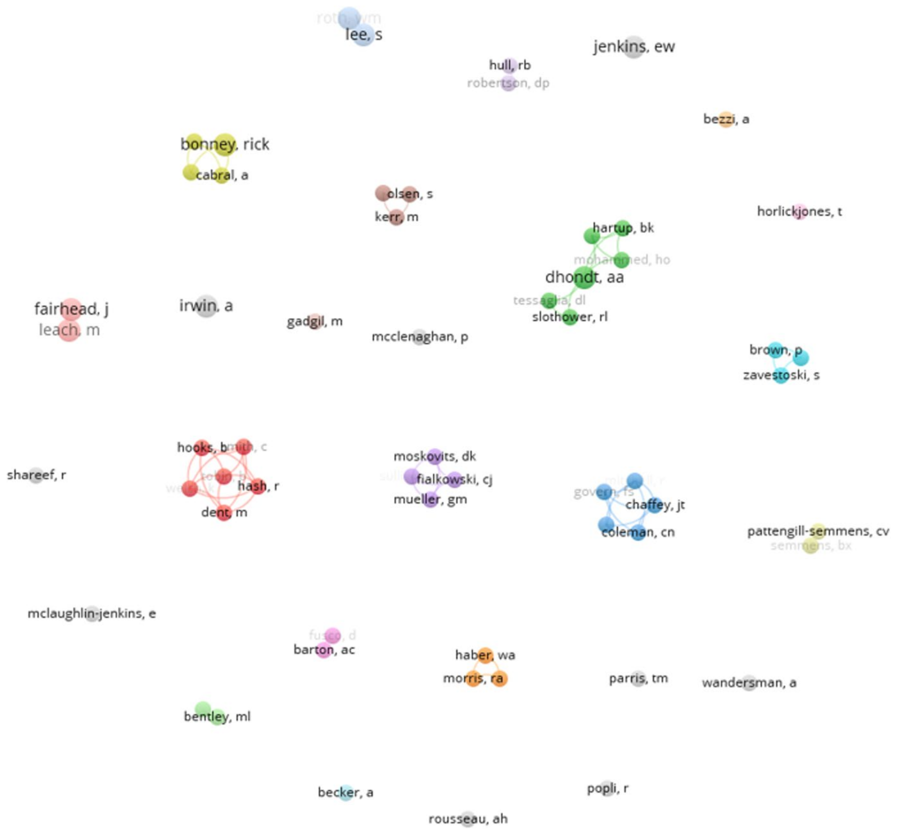


Fig. 3 Co-authorship pattern for data from 1995 to 2003

2003. It is a very early star-shaped formation (as per Table 2) prior to any 'silo-isation'. From 2003 on, larger clusters of co-authors begin to form. However, these typically remain siloed within single disciplines, chiefly Ecology (and later Astronomy), and their activity tends not to cross institutional boundaries (but does reveal a strong North American dominance). In 2003, the first clusters of more than five authors appear. Figure 3 shows that, the largest co-author networks (shown in red and green) were made up of: (1) six nutritionists at Mercer University in Macon, Georgia, centred on Hooks and, (2) six ecologists at Cornell University pursuing ornithological work centred on Dhondt. The next largest group (shown in blue) involved five medical researchers investigating radiation medicine including Chaffee and Coleman. The next largest network in 2003 (in purple in Fig. 3) involved four museum-based researchers in Illinois led by Moscovits. They similarly published within Ecology and were supported by close institutional colleagues. Another quad exists with Bonney (like Dhondt, who was also at Cornell), and three colleagues from the university's education department who had previously published in 2000.

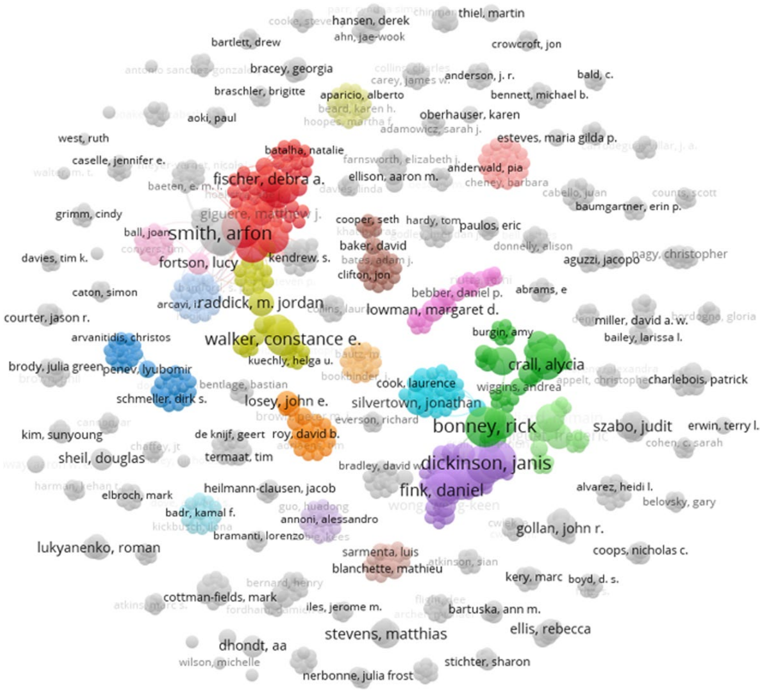


Fig. 4 Co-authorship pattern for cumulative data from 1995 to 2013

Irwin, having published in the Social Sciences, showed no linkage to and from other authors at this early stage.

Figure 4 shows that, as with the cumulative picture of 1995–2013, the overall picture of influential co-authors is still star-shaped and pulling in different directions (as per Table 2). Dhondt's and Muscovits' groups had faded from publishing influence—the former now at the edge of VOSviewer's vector space—while scholarship networks linked to Bonney (and Crall, both in green) grew denser, more closely linked to other Biology researchers like Dickinson and Fink but not in the very centre of the graph. Some degree of relative power and influence on the part of Bonney and his Ecology colleagues to shape future research agendas was shared with Astronomy researchers such as Smith and Fischer (in red) and to a lesser degree with other Biology colleagues such as Schmeller and Penev (in blue) who draw on different literature. Influential co-author networks in this star-shaped pattern are always in tension also with the more numerous dyads, triads and quads, etc. largely located at the periphery of these vector graphs. These peripheral formations coming to the centre over time are indicative of the potential strengthening of interdisciplinary research activity, i.e., their activity is further away from the joint puzzle solving occurring with researchers in the middle of the graph and is more akin to "parallel problem solving" (Raasch et al. 2013, 1139).

Simultaneously, by 2013, a new grouping had surfaced reflecting the influential work on the Galaxy Zoo project of astrophysicists Lintott and Schawinski, activity

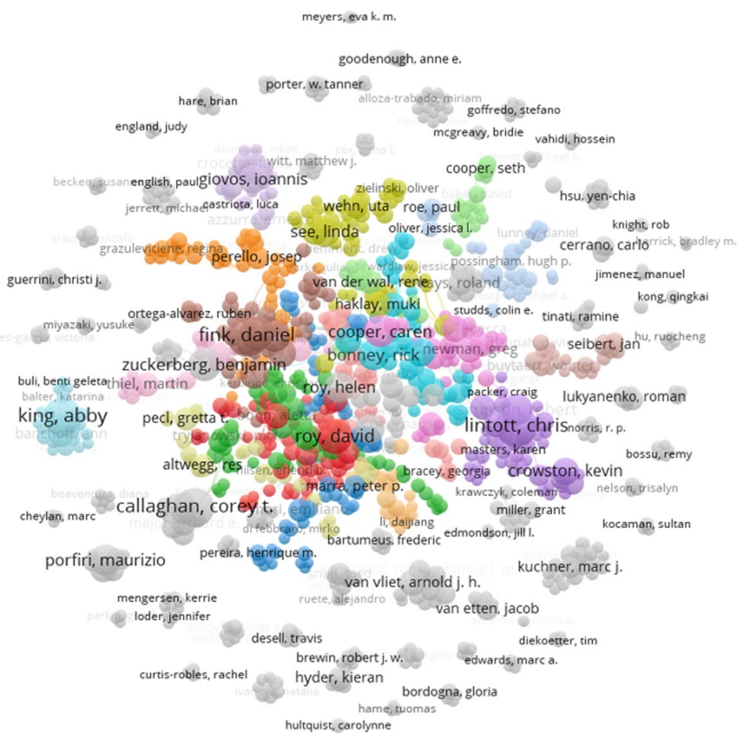


Fig. 5 Co-authorship pattern for cumulative data from 1995 to 2021

reflected in the 'Physics' percentage share in Appendix E (suppl. material). While Lintott's and Bonney's groups are near the centre of the graph, there is a small relative gap between them in the vector space (which grows wider in later years with neither gaining fuller overall influence nearer the centre of the map). This is illustrative of the quite different disciplinary literatures that each author network is drawing on and hence the lack of completeness of 'citizen science' and 'community science', and everything in between, as a disciplinary whole (the network pattern of which would look more like the 'complete' image from Table 2).

By 2021, the cumulative co-authoring pattern looks much busier (Fig. 5), but still start-shaped. Dominance in network strength of Biology-based activity appears greater (with the Social Science work of someone like Haklay appearing closer to Biology authors), but the gap between Astronomy researchers centred on Lintott (in purple) and everyone else remains. The overall network is lumpy and only partly *complete* further reflecting a star-shape now with a single star point out of place (as per Table 2). The greater distance between researchers (and those clusters not linked directly to the core of Biology co-authors) suggests that the pursuit of potentially more distanced research questions that are framed in alternative ontological and epistemological approaches.

A plotting of the cumulative co-citation network for these authors' works from 1995 to 2021 shows in an even starker way how the distribution of citations

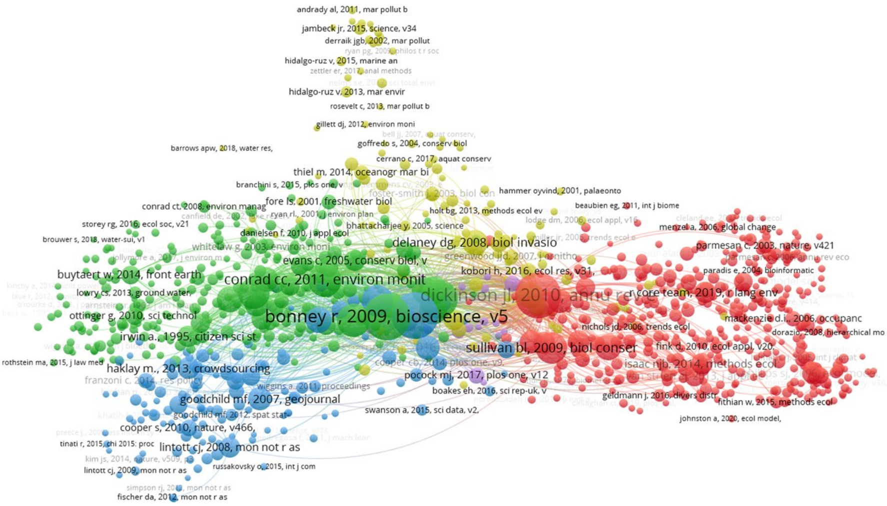


Fig. 6 Author co-citation pattern for publications cumulatively from 1995 to 2021

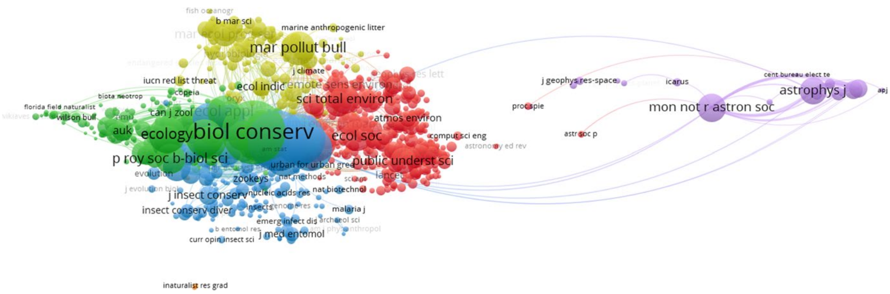


Fig. 7 Cumulative co-citation pattern between 1995 and 2021 by journal

appear to be being pulled apart in a star shape (and thus is far from coherent) (Fig. 6). For example, two highly cited Ecology documents, Dickinson et al. (2010) and Sullivan et al. (2009), near the centre of the diagram, have been labelled in red by VOSviewer. These items have plenty of co-citation associations stretching away from the centre of the vector space to the right. Similarly, a group of Ecology articles, but with different co-citations, centred on Bonney et al. (2009) and Bonney et al. (2014), has been grouped by VOSviewer in green, stretches off oppositely to the left of the image space. Other star-shaped arms stretch in different directions including one with Astronomy articles. To examine this in greater detail, VOSviewer was tasked with analysing journal co-citation occurrence cumulatively from 1995 to 2021 (Fig. 7). This result, which further reinforces the dominance of Ecology journals at the heart of network space, shows the disciplinary underpinning of the star shaped arms in previous figures—one arm (the yellow one) is based on marine research while another one (the red one) has a mixed basis of natural science journals (e.g. *Science of the Total Environment*) mixed with social science (e.g. *Public Understanding of Science*) and how far removed co-cited Astronomy journals are from these publications near the core of vector space.

To gain greater confidence in the picture being painted by the co-authorship and co-citation results, figures for discipline assortativity (*r*) were sought from co-citation proximity analysis in Pajek social network software covering the shape of the overall network for each year from 1995 to 2021 (cf. Raasch et al. 2013). Throughout the entire period, *r* was between −0.65 and −0.96, i.e., network assortativity was very low.[7] This suggests that all publications continue to form a heterogeneous rather than homogeneous body of knowledge and that the circumstances are not yet right for the formation of a unified body of new knowledge that would be more representative of Table 2's *complete* classification.

The qualitative content analysis of twelve highly cited publications in different disciplines (identified in Appendix A) confirmed the interpretation of the network data given above (Appendix B). Project activity was dominated in eight out of twelve publications by Bonney-style natural science approaches to citizen science, which refer primarily to citizen science as a 'research tool' (Dickinson et al. 2010), that offers 'cost-effectiveness' (Nelms et al. 2017) and is supported by volunteers who are 'amateur observers' (Bonney et al. 2009). The remaining four publications came from, or suggested affinity with, an Irwin-style approach to 'active' data collection (See et al. 2016), involving 'community-based monitoring' and 'collaboration' (Wals et al. 2014) and community 'empowerment' (Mahr et al. 2018). What this alternate orientation and its language means in practice was further examined in terms of:

1. who controls the design and analysis,
2. any claims to knowledge/utility,
3. which resources are thought to enable things to happen, and
4. the authors' characterisations of the nature of expertise in evidence.

In terms of this overall approach, all eight natural science publications identified professional scientists as being in control of the research design. This typically included a concern for developing "criteria for identifying data that contain systematic errors" (Bonney et al. 2009, 980–1), where participants are regarded as workers rather than citizens (e.g. Nelms et al. 2017). As such, they are:

> not involved in asking the original experimental questions, nor do [*sic*] they help to design the experimental procedure … [Instead] participants were following prescribed directions (Trumbull et al. 2000: 267).

This utilitarian orientation was also linked to a knowledge deficit approach concerning citizen scientists. Dickinson et al. (2010: 156), for example, suggested

7 The network figure in Pajek for 2021's cumulative data was -0.96.

that trained volunteers are not as good as professionals and were more like "undergraduate field assistants". Similarly, Lots et al. (2017: 225) report that "Citizen science does result in limited accompanying field observations".

Nevertheless, and despite these limitations, there is a clear sense that the approach is regarded as an 'indispensable' tool by many (Dickinson et al. 2010) that is "remarkably successful in advancing scientific knowledge" (Bonney et al. 2009: 977). Indeed, in some cases, the skills and contributions of citizen scientists were explicitly acknowledged. For example, the collective observational skills of citizen astronomers led to Willett et al.'s (2015: 2858) Galaxy Zoo project: containing "more than an order of magnitude more galaxies than the largest comparable expert-classified catalogue". And, likewise, for volunteer archaeologists, Lambers et al. (2019: 8) report that: "Citizen researchers … detect objects they have not been instructed to detect".

In terms of the barriers and enablers of citizen science activity, Silvertown (2009) and others stress that benefits accrue to teams who draw up 'simple and straightforward' protocols (Bonney et al. 2009; Willett et al. 2015; Lots et al. 2017; Nelms et al. 2017). Others expressed concern for technical matters such as large-scale database design (See et al. 2016) and improving data quality through the weeding out of false positives (Lambers et al. 2019).

By contrast, there was a broader focus on citizen and community empowerment through citizen science and community science from authors who included social science approaches. Mahr et al. (2018: 99) report that: "Citizen science reshapes hopes for a democratisation of scientific knowledge production through the empowerment of grassroots initiatives to conduct research". Both the Geography and Sustainability publications straddle natural science and social science orientations and in Appendix B, Wals et al. (2014: 584), for example, state that citizen science activity can be viewed as a public good: "that is generated through increasingly collaborative tools and resources". And, even in the very technically oriented archaeological case study from the humanities provided by Lambers et al. (2019: 13), the authors state: "Citizen researchers can make important contributions on multiple levels …: [including in] the research design step, by contributing their own research questions".

Such an approach, where the control of professional sponsoring scientists is loosened, is reflected in the different framings of expertise with these specific publications. These outputs make fewer distinctions between the expert analysts and the volunteers (Wals et al. 2014), and offer evidence of the social and historical context in which public trust in the expertise of experts, as well as the underlying values that experts represent, becoming severely eroded (Mahr et al. 2018). As such, this approach to citizen science and community science activity reflects the need to enable individual citizens to be critical thinkers and to "consider the effects and reasons for environmental issues" (Wals et al. 2014: 583). For example. Mahr et al. (2018: 100) claim that the social sciences and humanities have an especially important role to play in framing such activity because: "The potential for a growing (and shared) reflexivity of citizen science … requires critical engagement with the underlying assumptions of participatory research".

Against this backdrop, in the social science and humanities publications that we have selected, there is recognition that the key barriers and enablers of success are more than simply technical. Results also hinge on more open and empowering interpretations of who and what a citizen (and community) is and can achieve. As well as the practical guidance which all contributors offer in terms of overcoming barriers, Wals et al. (2014: 583) suggest that with environmental projects: "[it] provides a space to consider the social and the ethical and not just the technical". This is what Mahr et al. (2018: 99) mean when they talk about the growing success and take-up of citizen science which: "needs to be accompanied by increased reflexiveness in the field", a point that is redolent of the work of Arnstein (1969), and Callon et al. (2009) in terms of meaningful engagement between parties with different types of expertise.

Conclusions

The volume and continued growth in publications relating to citizen and community science mean that it is important to ask how this new epistemic territory is being carved out (and up) by different disciplinary traditions. Our bibliometric analyses show that, after an early period when no discipline was ascendant, the early relative dominance of biology-based outputs from 2004 has been declining steadily up to 2020 as outputs from several other disciplines have become more established (Fig. 2). This evolution, when analysed in terms of network assortativity (*r*), also reveals that, despite continuing attempts at interdisciplinarity, total global publishing efforts have always come from within a relatively small number of disciplines (Raasch et al. 2013; Pettibone et al. 2017). Indeed, if anything, research is currently moving towards increasingly siloed outputs which typically draw on past disciplinary, rather than new interdisciplinary, publishing efforts. This heterogeneous picture of clustered groups of authors, publications and journals (Figs. 5, 6 and 7) has been consistent throughout the timeline of publications since 1995, with continual negative assortativity, or *dissassortativity*, suggesting that citizen science and community science researchers are unable to form a more coherent and 'complete' epistemic territory for their work in recent years.

This lack of coherence is explained by our analysis of highly cited publications from the dominant disciplines and the different ways in which citizen science and community science are framed. We have shown that a distinct division has always existed between natural scientists pursuing a top-down approach to citizen science and those in the social sciences and humanities who are typically choosing to pursue a bottom-up approach to community science. The former approach tends to regard individual volunteers instrumentally in terms of the benefits to a project while the latter involves greater individual and collective empowerment on the part of community volunteers. This, in turn, leads to two distinctly different understandings of what might be taking place in practice. The top-down approaches that predominate in the natural sciences have a more utilitarian flavour, with citizen science volunteers a seen as an 'efficient' and 'cost-saving' tool that is 'indispensable' for data collection in numerous large-scale studies. In terms of expertise, these citizen science projects have, at times, characterised their volunteers as relatively unsophisticated workers for whom any training needs to be kept as simple as possible to minimise coding errors.

In contrast, the social science and humanities authors (including Geography and Sustainability researchers who have both natural and social science roots) are drawn towards a more bottom-up approach that leads to a quite different set of hoped-for outcomes including the democratisation of scientific knowledge. In these projects, emphasis is typically given to making public participation to be meaningful, rather than tokenistic, leading to a much greater concern with issues of power, participation and legitimacy running (Prainsack 2016) that are simply not present in the top-down projects. This distinction matters because genuinely co-created knowledge, felt by many to be the gold standard for citizen science practice and publications, appears much more likely to be produced in the more meaningful context of empowered citizenship. In future work, it would be interesting to analyse community-based definitions and their representation in the literature, including those that deliberately avoid the term citizen science (Cooper et al. 2021). Similarly, it would help to know more about the experiences of those actors who mediate between both worlds of institutionalized citizen science and grassroots initiatives (e.g. Mahr 2021).

How citizen science research will develop remains unclear, but our analysis of its contemporary epistemic territory suggests that it is divided rather than united. A more coherent and more interdisciplinary research agenda can only emerge if questions about the nature and purpose of citizen science can break away from what seem to be ever smaller disciplinary boundaries. Examples of these new questions include how to think about expertise and alternative expert paradigms (Prainsack 2016; Strasser et al. 2019), what kinds of expertise do volunteers and professional scientists bring to their contributions and how do citizens and scientists trust, value and understand each other's role? It seems we would do well to ask ourselves and our volunteers "what and who is science actually for?"

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

References

Adriaanse, Leslie S., and Chris Rensleigh. 2013. Web of Science, Scopus and Google Scholar—A content comprehensiveness comparison. *The Electronic Library* 31(6): 727–744.

Allen, Barbara L. 2018. Strongly participatory science and knowledge justice in an environmentally contested region. *Science, Technology, and Human Values* 43(6): 947–971.

Andrés, Ana. 2009. *Measuring academic research: How to undertake a bibliometric study*. Amsterdam: Elsevier.

Arnstein, Sherry R. 1969. A ladder of citizen participation. *Journal of the American Institute of Planners* 35(4): 216–224.

Bautista-Puig, Núria, Daniela De Filippo, Elba Mauleón, and Elías Sanz-Casado. 2019. Scientific landscape of citizen science publications: Dynamics, content and presence in social media. *Publications* 7(1): 12.

Benyei, Petra, Manuel Pardo-de-Santayana, Laura Aceituno-Mata, Laura Calvet-Mir, et al. 2021. Participation in citizen science: Insights from the CONECT-e case study. *Science, Technology, and Human Values* 46(4): 755–788.

Bonney, Rick. 1996. Citizen science: A lab tradition. *Living Bird* 15(4): 7–15.

Bonney, R., C.B. Cooper, J. Dickinson, S. Kelling, T. Phillips, K.V. Rosenberg, and J. Shirk. 2009. Citizen science: A developing tool for expanding science knowledge and scientific literacy. *BioScience* 59(11): 977–984. https://doi.org/10.1525/bio.2009.59.11.9.

Bonney, R., J.L. Shirk, T.B. Phillips, A. Wiggins, H.L. Ballard, A.J. Miller-Rushing, and J.K. Parrish. 2014. Next steps for citizen science. *Science* 343 (6178): 1436–1437.

Börner, K., C. Chen, and K.W. Boyack. 2003. Visualizing knowledge domains. *Annual Review of Information Science and Technology* 37: 179–255.

Boyack, Kevin W., Richard Klavans, and Katy Börner. 2005. Mapping the backbone of science. *Scientometrics* 64(3): 351–374.

Brown, P. 1987. Popular epidemiology: Community response to toxic waste induced disease in Woburn, Massachusetts and other sites. *Science, Technology, and Human Values* 12(3–4): 76–85.

Brown, P. 1992. Toxic waste contamination and popular epidemiology: Lay and professional ways of knowing. *Journal of Health and Social Behavior* 33: 267–281.

Brown, P. 1993. When the public knows better: Popular epidemiology challenges the system. *Environment* 35(8): 16–21.

Brown, P. 1997. Popular epidemiology revisited. *Current Sociology* 45(3): 137–156.

Callon, Michel, Pierre Lascoumes, and Yannick Barthe. 2009. *Acting in an uncertain world—An essay on technical democracy*. Cambridge, MA: MIT Press.

Chubin, Daryl E., Alan L. Porter, Frederick Rossini, and Terry Connolly. 1986. *Interdisciplinary analysis and research: Theory and practice of problem-focused research and development*. Broxburn, Fife: Lomond.

Cooper, C.B., and B.V. Lewenstein. 2016. Two meanings of citizen science. In *The rightful place of science: Citizen science*, ed. D. Cavalier, and E.B. Kennedy, 51–62. Tempe: Consortium for Science, Policy & Outcomes.

Cooper, C.B., C.L. Hawn, L.R. Larson, J.K. Parrish, et al. 2021. Inclusion in citizen science: The conundrum of rebranding. *Science* 372(6549): 1386–1388.

Cornwell, Myriah L., and Lisa M. Campbell. 2012. Co-producing conservation and knowledge: Citizen-based sea turtle monitoring in North Carolina, USA. *Social Studies of Science* 42(1): 101–120.

Crane, Diana. 1972. *Invisible colleges; Diffusion of knowledge in scientific communities*. Chicago: University of Chicago Press.

Davidson Frame, J., and Mark P. Carpenter. 1979. International research collaboration. *Social Studies of Science* 9(4): 481–497.

de Moya-Anegón, Félix., Benjamín Vargas-Quesada, Zaida Chinchilla-Rodríguez, Elena Corera-Álvarez, Francisco J. Munoz-Fernández, and Victor Herrero-Solana. 2007. Visualizing the marrow of science. *Journal of the American Society for Information Science and Technology* 58(14): 2167–2179.

Den Broeder, L., J. Devilee, H. Van Oers, A.J. Schuit, and A. Wagemakers. 2018. Citizen science for public health. *Health Promotion International* 33(3): 505–514. https://doi.org/10.1093/heapro/daw086.

Dickinson, J.L., B. Zuckerberg, and D.N. Bonter. 2010. Citizen science as an ecological research tool: Challenges and benefits. *Annual Review of Ecology, Evolution, and Systematics* 41: 149–172.

Dosemagen, Shannon, and Alison J. Parker. 2019. Citizen science across a spectrum: Broadening the impact of citizen science and community science. *Science and Technology Studies* 32(2): 24–33.

Eitzel, Melissa, Jessica Cappadonna, Chris Santos-Lang, Ruth Duerr, et al. 2017. Citizen science terminology matters: Exploring key terms. *Citizen Science: Theory and Practice* 2(1): 1–20.

Epstein, S. 1996. *Impure science: AIDS, activism, and the politics of knowledge*. Berkeley: University of California Press.

Faust, Katherine. 1997. Centrality in affiliation networks. *Social Networks* 19(2): 157–191.

Gmür, Markus. 2003. Co-citation analysis and the search for invisible colleges: A methodological evaluation. *Scientometrics* 57(1): 27–57.

Haklay, Muki. 2013. Citizen science and volunteered geographic information: Overview and typology of participation. In *Crowdsourcing geographic knowledge*, eds. D. Sui, S. Elwood, and M. Goodchild, 105–122. Berlin: Springer.

Heigl, Florian, Barbara Kieslinger, Katharina T. Paul, Julia Uhlik, and Daniel Dörler. 2019. Opinion: Toward an international definition of citizen science. *Proceedings of the National Academy of Sciences* 116(17): 8089–8092.

Irwin, A. 1995. *Citizen Science: A Study of People, Expertise and Sustainable Development*. London: Psychology Press.

Jonsen, Albert R. 2004. The history of bioethics as a discipline. In *Handbook of bioethics*, ed. Albert R. Jonsen, 31–51. Berlin: Springer.

Kasperowski, Dick, and Thomas Hillman. 2018. The epistemic culture in an online citizen science project: Programs, antiprograms and epistemic subjects. *Social Studies of Science* 48(4): 564–588.

King, Abby C., Sandra J. Winter, Jylana L. Sheats, Lisa G. Rosas, et al. 2016. Leveraging citizen science and information technology for population physical activity promotion. *Translational Journal of the American College of Sports Medicine* 1(4): 30.

Knoke, David, and Song Yang. 2008. *Social network analysis*, vol. 154. Thousand Oaks: Sage.

Knorr Cetina, Karin. 1999. Epistemic cultures: How the sciences make knowledge. Cambridge, MA: Harvard University Press.

Lambers, Karsten, Wouter B. Verschoof-van der Vaart, and Quentin P.J. Bourgeois. 2019. Integrating remote sensing, machine learning, and citizen science in Dutch archaeological prospection. *Remote Sensing* 11(7): 794.

Leydesdorff, Loet, and Olga Amsterdamska. 1990. Dimensions of citation analysis. *Science, Technology, and Human Values* 15(3): 305–335.

Leydesdorff, Loet, and Henry Etzkowitz. 1996. Emergence of a Triple Helix of university—Industry—Government relations. *Science and Public Policy* 23(5): 279–286.

Leydesdorff, Loet, and Thomas Schank. 2008. Dynamic animations of journal maps: Indicators of structural changes and interdisciplinary developments. *Journal of the American Society for Information Science and Technology* 59(11): 1810–1818.

Leydesdorff, Loet, Caroline S. Wagner, and Lutz Bornmann. 2018. Betweenness and diversity in journal citation networks as measures of interdisciplinarity—A tribute to Eugene Garfield. *Scientometrics* 114(2): 567–592.

Lots, Froukje A.E., Paul Behrens, Martina G. Vijver, Alice A. Horton, and Thijs Bosker. 2017. A large-scale investigation of microplastic contamination: Abundance and characteristics of microplastics in European beach sediment. *Marine Pollution Bulletin* 123(1–2): 219–226.

Mahr, Dana. 2021. *Thai Baan research: Locality as a key for diversity in the knowledge of experience*. Singapore: Palgrave Macmillan.

Mahr, Dana, Claudia Göbel, Alan Irwin, and Katrin Vohland. 2018. Watching or being watched? Enhancing productive discussion between the citizen sciences, the social sciences and the humanities. In *Citizen science: Innovation in open science, society and policy*, eds. S. Hecker, M. Haklay, A. Bowser, Z. Makuch, J. Vogel, and A. Bonn. London: UCL Press.

Meho, Lokman I., and Kiduk Yang. 2006. A new era in citation and bibliometric analyses: Web of Science, Scopus, and Google Scholar. arXiv preprint https://arxiv.org/abs/cs/0612132.

Nelms, S.E., C. Coombes, L.C. Foster, T.S. Galloway, et al. 2017. Marine anthropogenic litter on British beaches: A 10-year nationwide assessment using citizen science data. *Science of the Total Environment* 579: 1399–1409.

Ninkov, Anton, Jason R. Frank, and Lauren A. Maggio. 2021. Bibliometrics: Methods for studying academic publishing. *Perspectives on Medical Education* 11: 1–4.

Ottinger, G. 2010. Buckets of resistance: Standards and the effectiveness of citizen science. *Science, Technology, and Human Values* 35(2): 244–270.

Pettibone, Lisa, Katrin Vohland, and David Ziegler. 2017. Understanding the (inter) disciplinary and institutional diversity of citizen science: A survey of current practice in Germany and Austria. *PLoS ONE* 12(6): 1–16.

Prainsack, Barbara. 2016. Understanding participation: The 'citizen science'of genetics. In *Genetics as social practice*, eds. B. Prainsack, S. Schicktanz, and G. Werner-Felmayer, 147–164. Farnham: Ashgate.

Raasch, Christina, Viktor Lee, Sebastian Spaeth, and Cornelius Herstatt. 2013. The rise and fall of interdisciplinary research: The case of open source innovation. *Research Policy* 42(5): 1138–1151.

Roy, H.E., M.J.O. Pocock, C.D. Preston, D.B. Roy, J. Savage, J.C. Tweddle, and L.D. Robinson. 2012. Understanding citizen science and environmental monitoring: final report on behalf of UK environmental observation framework.

See, Linda, Peter Mooney, Giles Foody, Lucy Bastin, et al. 2016. Crowdsourcing, citizen science or volunteered geographic information? The current state of crowdsourced geographic information. *ISPRS International Journal of Geo-Information* 5(5): 55.

Shirk, J.L., H.L. Ballard, C.C. Wilderman, T. Phillips, et al. 2012. Public participation in scientific research: A framework for deliberate design. *Ecology and Society* 17(2): 29. https://doi.org/10.5751/es-04705-170229.

Shrum, Wesley, W. Joel Genuth, Bernard Carlson, and Ivan Chompalov. 2007. *Structures of scientific collaboration*. Cambridge, MA: MIT Press.

Silvertown, J. 2009. A new dawn for citizen science. *Trends in Ecology and Evolution* 24(9): 467–471. https://doi.org/10.1016/j.tree.2009.03.017.

Small, Henry. 1973. Co-citation in the scientific literature: A new measure of the relationship between two documents. *Journal of the American Society for Information Science* 24(4): 265–269.

Stevens, Matthias, Michalis Vitos, Julia Altenbuchner, Gillian Conquest, Jerome Lewis, and Muki Haklay. 2014. Taking participatory citizen science to extremes. *IEEE Pervasive Computing* 13(2): 20–29.

Strasser, Bruno, Jérôme Baudry, Dana Mahr, Gabriela Sanchez, and Elise Tancoigne. 2019. 'Citizen science?' Rethinking science and public participation. *Science and Technology Studies* 32(2): 52–76.

Sullivan, B.L., C.L. Wood, M.J. Iliff, R.E. Bonney, D. Fink, and S. Kelling. 2009. eBird: A citizen-based bird observation network in the biological sciences. *Biological Conservation* 142 (10): 2282–2292.

Tauginienė, Loreta, Eglė Butkevičienė, Katrin Vohland, Barbara Heinisch, et al. 2020. Citizen science in the social sciences and humanities: the power of interdisciplinarity. *Palgrave Communications* 6(1): 1–11.

Trumbull, Deborah J., Rick Bonney, Derek Bascom, and Anna Cabral. 2000. Thinking scientifically during participation in a citizen-science project. *Science Education* 84(2): 265–275.

Van den Besselaar, Peter, and Loet Leydesdorff. 1996. Mapping change in scientific specialties: A scientometric reconstruction of the development of artificial intelligence. *Journal of the American Society for Information Science* 47(6): 415–436.

Wals, Arjen, Michael Brody, Justin Dillon, and Robert B. Stevenson. 2014. Convergence between science and environmental education. *Science* 344(6184): 583–584.

Wasserman, Stanley, and Katherine Faust. 1994. *Social network analysis: Methods and applications*. Cambridge, UK: Cambridge University Press.

Wiggins, Andrea, and Kevin Crowston. 2012. Goals and tasks: Two typologies of citizen science projects. In *2012 45th Hawaii international conference on system sciences*.

Wilderman, Candie C. 2007. Models of community science: Design lessons from the field. In *Citizen science toolkit conference*. Ithaca, NY: Cornell Laboratory of Ornithology.

Willett, Kyle W., Kevin Schawinski, Brooke D. Simmons, Karen L. Masters, et al. 2015. Galaxy Zoo: The dependence of the star formation–stellar mass relation on spiral disc morphology. *Monthly Notices of the Royal Astronomical Society* 449(1): 820–827.