CITIZEN SCIENCE:
THEORY AND PRACTICE

A Citizen Science Community of Practice: Relational Patterns Contributing to Shared Practice

RESEARCH PAPER

]u[ubiquity press

CARLA SBROCCHI
GRETTA PECL
INGRID VAN PUTTEN
PHILIP ROETMAN

*Author affiliations can be found in the back matter of this article

ABSTRACT

Citizen science networks are a recent global phenomenon, with associated communities of practice that have emerged to support growth in the field and the development of practices. Effective communities of practice are dependent on the interactions from the social network underpinning the community. We examined the Australian citizen science practitioner network, using a combined social network analysis and survey approach. Our goal was to understand the structure and characteristics of this network, to establish who participates in this network, where and how interactions occur, and explore what participation achieves for the users. The Australian citizen science practitioner network has benefited from face-to-face citizen science events to make important connections that have been leveraged to benefit other working relationships and positive outcomes, especially for early-career practitioners and women within the network. How the community of practice continues to navigate successful knowledge exchange across society and science, whether through interactions in face-to-face or virtual settings, will need to be addressed as the community continues to grow in scope and size. In particular, the network will need to consider supporting key individuals who play important bridging functions across the citizen science practitioner network. The emergence of transdisciplinarity amongst those working in citizen science is a promising property of this learning community that is worth working strategically to maintain.

CORRESPONDING AUTHOR:
Carla Sbrocchi
University of Technology Sydney, AU
carla.sbrocchi@uts.edu.au

KEYWORDS:
citizen science; communities of practice; conferences; knowledge sharing; transdisciplinarity; science-society interface

TO CITE THIS ARTICLE:
Sbrocchi, C, Pecl, G, van Putten, I and Roetman, P. 2022. A Citizen Science Community of Practice: Relational Patterns Contributing to Shared Practice. *Citizen Science: Theory and Practice,* 7(1): 3, pp. 1–14. DOI: *https://doi.org/10.5334/cstp.358*

INTRODUCTION

Within the past few years, several organisations across the globe have emerged to support a growing number of networks of citizen scientists (Storksdieck et al. 2016), whose goals include building expertise amongst members through sharing of knowledge (Gobel et al. 2016). An essential component of this strategy involves strengthening relationships amongst members of the networks so they can assist each other and work together on projects that advance learning within the field (ACSA 2016). The emergence of shared interest often results in communities of practice, which are typically informal, self-organising groups of individuals who advance their concerns or interests through regular interactions (Wenger, McDermott, and Snyder 2002; Riel and Polin 2004). Interactions amongst some members of these global citizen science networks has resulted in a growing interest in the practice of citizen science, that is, the management and support of citizen science programs. Those who take on these roles are termed practitioners, and we define them as those who manage citizen science groups, or support citizen science programs through research, leadership, operational or monetary means. Involvement in citizen science is often motivated by a desire to inform science and policy, to improve buy-in, to manage public engagement, to advance scientific knowledge, to build partnerships, and for institutional promotion and publicity (Geoghegan et al. 2016). However, what motivates citizen science practitioners to engage in a practitioner community of practice is yet to be described, as is a description of how relationships develop or the characteristics of typical interactions.

Interactions between members of communities of practice are facilitated through social networks. A successful social network will augment the capacities of the individual members, and can yield collaborations, the giving and receiving of information and advice, and facilitate innovations in practice (Bodin, Crona, and Ernstson 2006; Crona and Bodin 2006; Bodin and Crona 2009; Bodin and Prell 2011; Hayat and Mo 2014; Lungeanu and Contractor 2015; Bodin 2017). In the context of citizen science, social networks are developed to co-produce knowledge and to link citizen scientists to policy and practice (Hecker et al. 2018; Nascimento et al. 2018; Vincent et al. 2018). This is, to some degree, dependent on the characteristics of the social network, on the opportunities to interact, and on the nature of the interactions. Consequently, as networks emerge and resources are invested, it will be important to understand the effectiveness and benefits of communities of practice.

We use an Australian case study to explore the interactions of citizen science practitioners. We have a unique situation in that some of the authors of this research (CS, GP, and PR) have been involved in the Australian citizen science practitioner network since its inception, and have captured the events and participation within the network as they emerged (see Supplemental Box 1 in Appendix 2: Summaries of Information on Early Development of the Australian Citizen Science Practitioners Network). To date, three open, national face-to-face meetings (***Figure 1***) have provided explicit opportunities for those interested in citizen science to come together and interact.

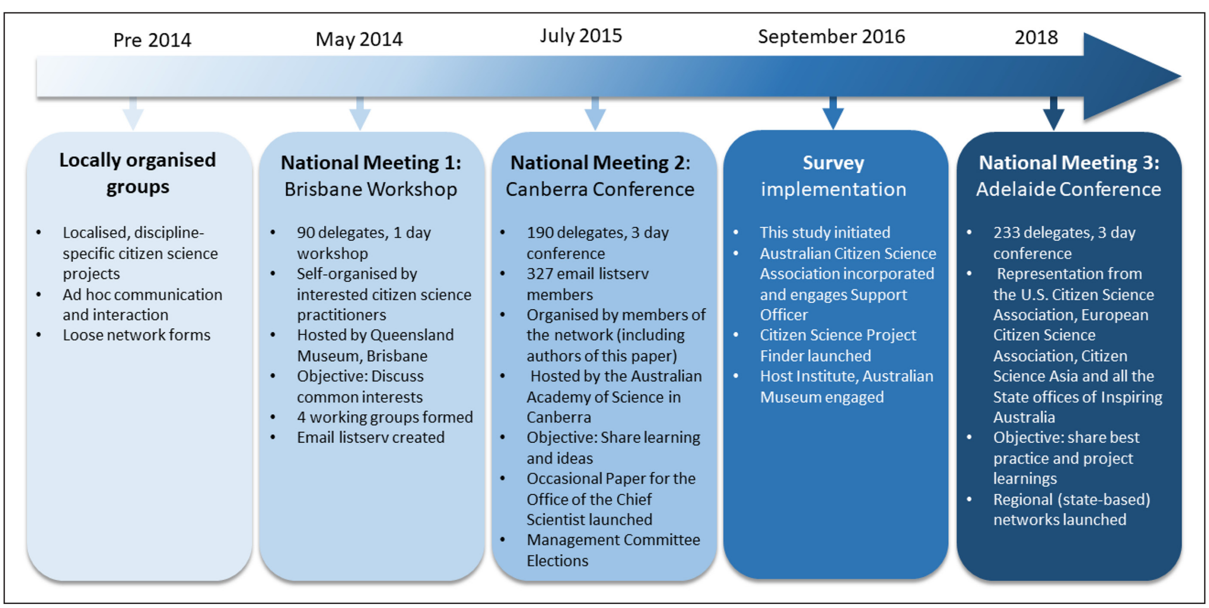


Figure 1 Timeline of events of national citizen science meetings and survey implementation. Created from material provided by Australian Citizen Science Association, *https://citizenscience.org.au/*.

Our study was initiated during a period of rapid expansion of citizen science projects and networks in Australia (Sbrocchi 2014; Pecl et al. 2015). We used a social network analysis and responses from an online survey to gain insight into interactions amongst Australian citizen science practitioners and to understand current network capacity and future practitioner needs. We use Wenger, McDermott, and Snyder's (2002) three areas of communities of practice to frame our analysis: people, practice, and domain. More specifically, we ask: (1) Who is interacting in the community of practice, and what characteristics are important for forging and maintaining interactions? (2) What are the ways of doing things and forms of knowledge that comprise the shared practice? (3) What is the common thread that holds the community together?

METHODS

SURVEY AND DATA

Our study specifically targeted those who considered themselves practitioners (previously defined) as opposed to participants in citizen science projects. However, at the time of this study, a database of practitioners and/or citizen scientists did not exist, so we used a variety of strategies to gain our sample.

At the time of the survey, more than 327 citizens science practitioners subscribed to an informal citizen science email list service (administered by the Australian Citizen Science Association), and had 265 active projects listed on the Australian Citizen Science ProjectFinder (*https://biocollect.ala.org.au/acsa*). We initially sent a non-personalised email with a request to participate in our research on connections between citizen science practitioners through the email list service. Those who were willing to participate were asked to register their interest through a Google Form, and submit their name, their organization, the name of the citizen science project they associate with most, the state in which they resided, and their disciplinary background. It was made clear to participants that by registering their details in the Google Form they were giving consent to use their personal information in the survey as part of the research project. In total, 105 people agreed to participate, and their names were included in the final survey, which was administered through SurveyMonkey (Survey Monkey 2016) in September 2016. Reminder emails were sent, and the survey closed in December 2016. Incomplete surveys were excluded from the analysis. A total of 75 respondents returned a useable survey.

Survey Monkey data was collated in an Excel spreadsheet, where general frequency statistics were calculated (Supplemental Tables 2–5 in Appendix 4: Survey Results). Open-ended question responses were coded and collated thematically (Supplemental Tables 13–15 in Appendix 4: Survey Results). Coding was checked by two other researchers to ensure inter-coder reliability. Networks were visualised and analysed in Cytoscape (version 3.8.2), and further statistical analysis on respondent data was performed in R (version 4.1.0).

FRAMEWORK FOR ANALYSIS

Wenger, McDermott, and Snyder (2002) describe communities of practice as having a similar basic foundation: a domain of knowledge (a common thread that holds the community together), a community of people (a common value that promotes trust and relationships), and a shared practice (a common set of ways of doing things they develop to be effective in their domain). Our study is primarily concerned with the community of people as a key component of an effective community of practice, but also touches on knowledge and practice to better understand the community now and its needs into the future.

We utilised social network analysis as well as results from an online survey (Supplemental Appendix 1: Survey Questions) to answer questions related to Wenger's communities of practice: The people aspect was addressed through research questions 1a–c, knowledge in research question 2, and shared practice in research question 3 (***Table 1***).

To understand the shape and size of the citizen science practitioner network as key elements of the structure of the network, we employed standard (individual- and network-level) frequencies and network statistics. We evaluated if there were any gender-, location-, and discipline-related differences in respondent's social status in the network (individual network measures for degree, betweenness, and clustering coefficient). We gained insight into the knowledge aspect on the basis of the responses to three separate closed survey questions, which assessed the strength, nature, and intensity of each interaction. We assessed the quality of the connections at the level of the whole network and tested for demographic differences. Further details are supplied in Supplemental Appendix 3: Methods Statements.

RESULTS

The Australian citizen science practitioner network is an active and maturing community of practice, showing broad and diverse connections amongst members. Members gain value from interacting, but members receive different benefits depending on their purpose in engaging. Below we present results for our key research questions in separate sections (all data available in Supplemental Files).

RESEARCH QUESTION	METHOD/DATA SOURCE	INFORMATION COLLECTED
1A. What is the structure of the practitioners' network?	Network statistics for the whole network	How well-connected is the practitioner network
1B. Who is producing and sharing knowledge?	Network centrality measures for individuals in the network (degree, betweenness, clustering, shortest path) (Supplemental Table 1) Assessment of difference for demographic indicators	Information on social status in the network Demographic differences in social status (i.e., by gender, location, and discipline)
1C. How is the community maturing?	Network centrality measures for individuals in the network (degree, betweenness, clustering, shortest path) (Supplemental Table 1) Assessment of difference for formal status indicators Survey question on attending meetings	Differences in social status according to age (proxy for career stage) and committee membership (proxy for experience within citizen science community) Social status according to meeting attendance
2. What are the ways of doing things and products that form the shared practice?	Closed survey questions	Differences in the nature, intensity, and frequency of the interactions Types of products in the interaction, e.g. ideas, tools, frameworks, papers (closed questions) Quality of interactions
3. What is the common thread that holds this community together (the knowledge domain)?	Open-ended survey question	Benefits of connections grouped according to theme Difficulties of maintaining connections grouped according to theme

Table 1 Analytical methods for this study.

Seventy-five respondents returned a useable survey, and they had a total of 723 interactions (links) between them. We received a well-balanced response from across Australia's states and the Australian Capital Territory (ACT), with the Northern Territory an exception. Five international citizen science practitioners also responded to the survey. However, because these international respondents likely had a special connection to Australian citizen science practitioners, our analysis cannot draw any robust conclusions for this group and is therefore not further discussed in detail. Our sample represents 23% of the 327 members of the Australian Citizen Science Association network. However, there may be inclusion or exclusion bias in our survey as the true size of the citizen science network may be larger. We acknowledge structural holes in our network are possible as a consequence of the empirical approach we have adopted (Burt 1992).

Comparing the survey data to an earlier period of the network (Supplemental Box 2, Appendix 2: Summaries of Information on Early Development of the Australian Citizen Science Practitioners Network), the largest group of respondents continue to be from the most populous states of NSW (26%), Victoria (20%), and Queensland (15%), but our survey indicates a growing group of practitioners across other parts of Australia (9.5% from both South Australia and Australian Capital Territory, and 7% from Tasmania and from Western Australia). The majority of respondents had a science background (55 respondents, 76%), more women than men responded (44 versus 31), and most respondents were between 31 and 50 years of age.

A total of 12 of the 75 survey respondents attended both the first and second national meetings that preceded the development of the network, with 34 having attended another citizen science event as well (Supplemental Table 12, Appendix 4: Survey Responses). Female attendance at meetings was higher than male attendance (e.g., at the 2015 conference, 62% were women).[1]

THE COMMUNITY OF PEOPLE

Network structures are categorised as random networks (Watts and Strogatz 1998; Watts 1999); small-world networks, which exhibit a higher degree of clustering than random networks (Watts 1999); or scale-free networks (Barabási and Albert 1998; Albert and Barabasi 2000; Albert and Barabási 2002) that have hubs with individuals who are highly connected (Barabási et al. 2002). In the citizen science practitioner network, the clustering coefficient was 0.498 (***Figure 2***), and the characteristic path length for the whole network was 2.196, suggesting the network resembles a small-world network. Because there are a number of highly connected people (discussed below), it is possible that the network will become a scale-free network as it grows over time.

Overall, the citizen science practitioner network comprises a highly connected group of respondents, but with some more connected than others (***Figure 3***).

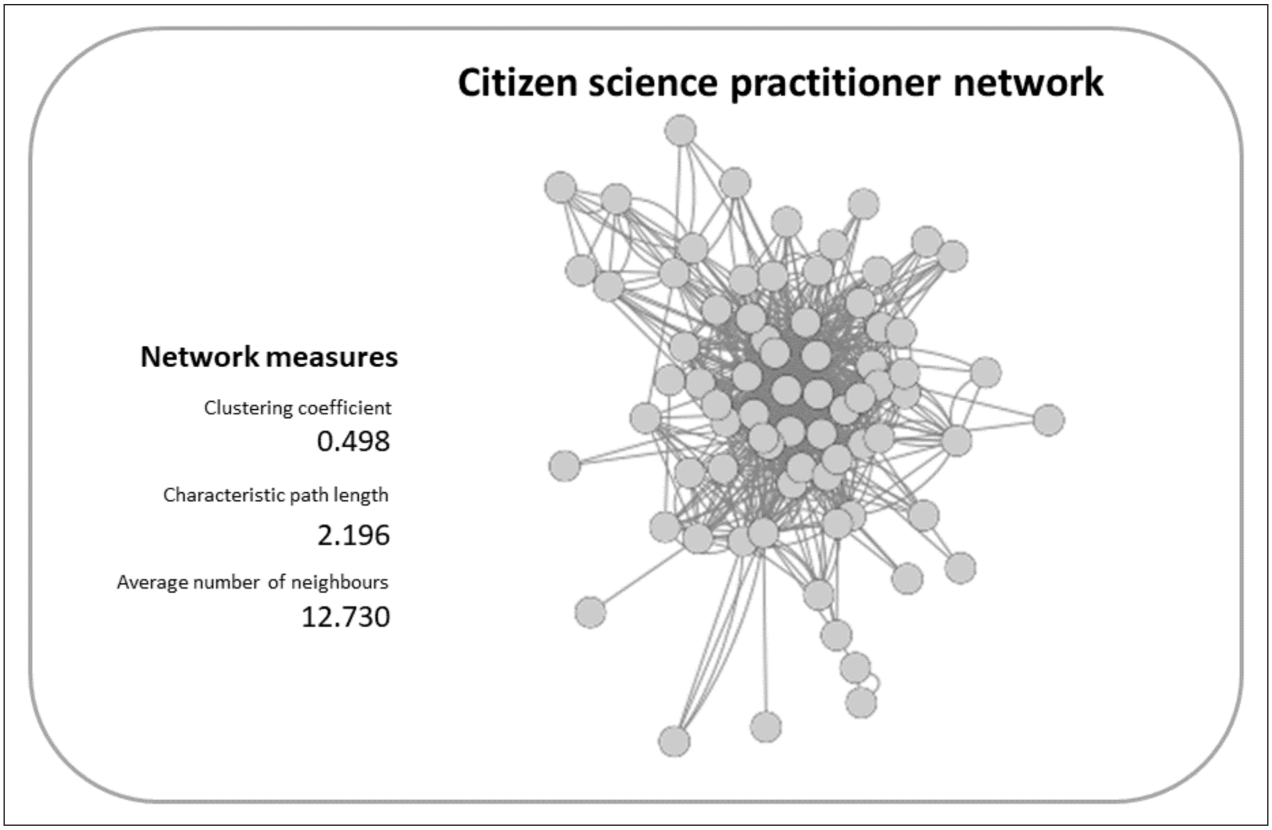


Figure 2 Graphic representation of the citizen science practitioner network and network statistics.

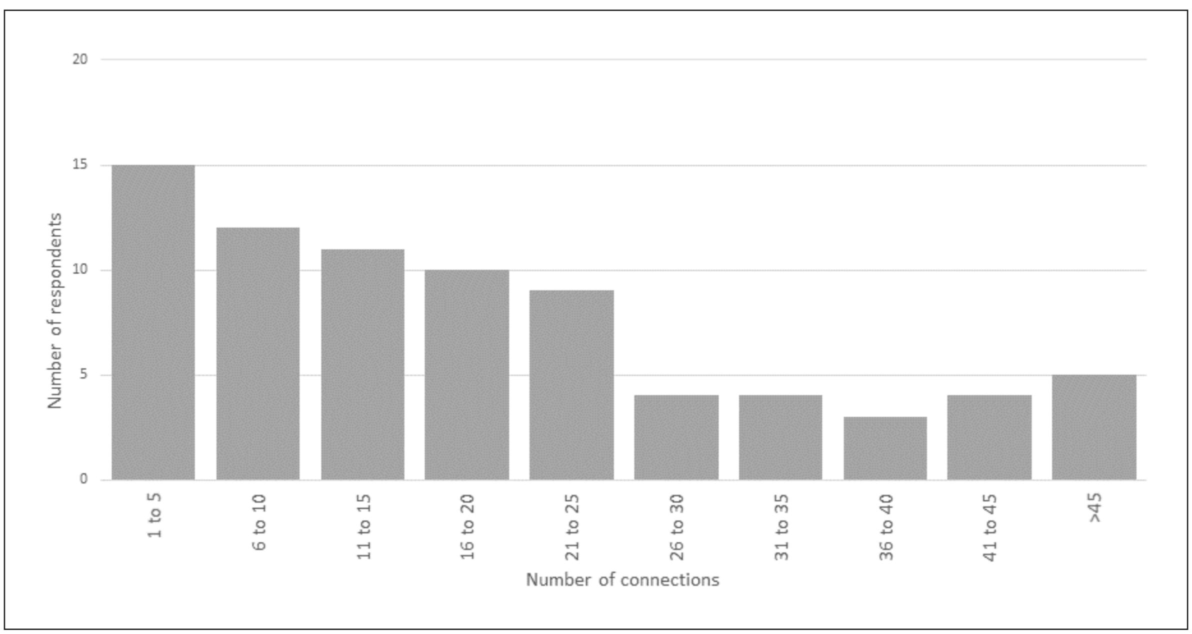


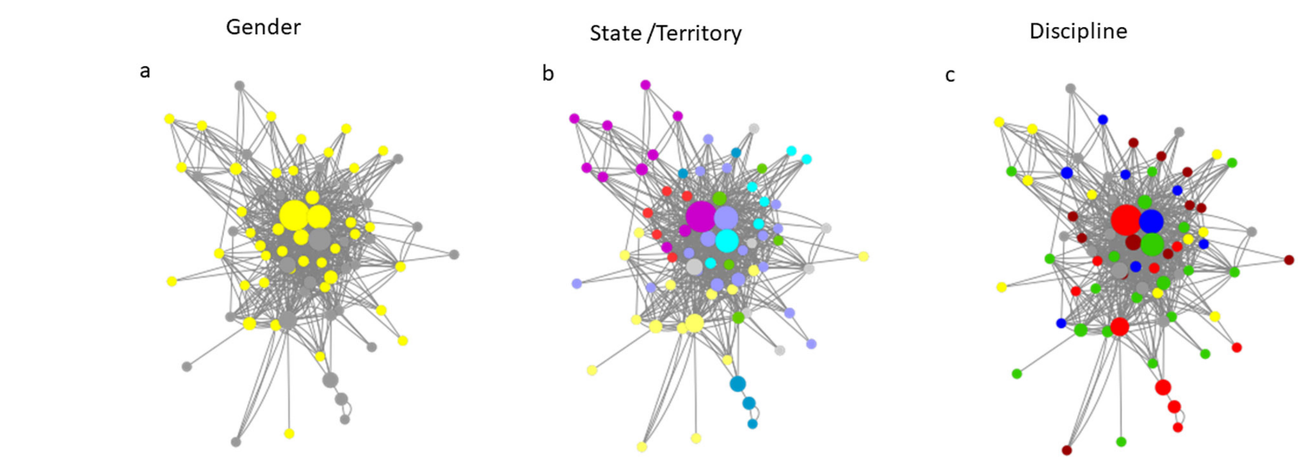
Figure 3 The number of connections for individuals in the citizen science practitioner network (75 respondents).

Individuals have, on average, 19.5 connections with others in the network. The most connected person had 84 connections, 65 more than the network average.

Citizen science practitioners are from a range of areas across science, policy, and community (this study, and unpublished data; see Supplemental Box 2, Appendix 2: Summaries of Information on Early Development of the Australian Citizen Science Practitioners Network). The community of practice was described as offering important opportunities to develop relationships across professional or disciplinary boundaries (see also Supplemental Figure 1, Appendix 4: Survey Results). One respondent remarked, "As a researcher, I get benefits from interacting with others working in similar areas, regardless of their status (citizen scientist, professional researcher, whatever)." To these practitioners, collaborating with others in citizen science actually means working in a transdisciplinary way—not only talking about it.

The interactions amongst the practitioners' network do not appear to be strongly influenced by geographic (State) boundaries, but they do appear to be influenced by disciplinary backgrounds and gender (***Figure 4***). Those who had biological science backgrounds (marine science, zoology, botany) had a higher average degree score and higher betweenness scores than the other disciplines (***Figure 4c***), and women generally had more network connections than men and a slightly higher clustering coefficient (0.642 versus 0.544) and shorter path length (2.002 versus 2.172) (***Figure 4a***). The position of women within the citizen science network was slightly more central than it was for male respondents. Although the network has many highly connected women, female practitioners were just as likely to interact with men as they were with other women (Supplemental Table 7, Appendix 4: Survey Results). Men, however, were more likely to interact with women than with other men—but this could be a consequence of the greater number of women in the sample.

Indicators of a maturing community of practice can be found in the contribution of people from different age groups and from different levels of experience, which we refer to as their formal status (as defined in ***Table 1***). The Australian practitioner network shows evidence of formal status having some influence on network interactions. When practitioners had a visible role, for example, through speaking engagements or committee positions (n = 12), they had on average almost three times as many connections as practitioners who had no visible involvement (47.08 compared with 14.21; see Supplemental Table 10, Appendix 4: Survey Results). When using age as a proxy for career stage, we found that early-career practitioners (less than 40 years old) had more connections (22.56) than their mid- and late-career counterparts (19.43 and 13.58 respectively; Supplemental Table 9, Appendix 4: Survey Results). The interactions amongst the younger cohort were also more tightly clustered (clustering coefficient of 0.65) than the older groups, and their betweenness centrality was also higher (0.018). Those in their early- and mid-career stages, and those with a visible involvement in the network, were comparatively more central in the network.



Average social status by group

	Female	Male
Betweenness	0.015	0.015
Clustering coefficient	0.642	0.544
Degree	22.116	15.968
Shortest path length	2.002	2.172

	ACT	NSW	QLD	SA	Tas	Vic	WA	Int
Betweenness	0.011	0.016	0.024	0.021	0.012	0.011	0.016	0.001
Clustering coefficient	0.481	0.685	0.550	0.697	0.548	0.556	0.438	0.770
Degree	15.571	24.895	21.000	23.857	22.400	14.600	6.600	20.400
Shortest path length	2.117	1.954	2.066	1.930	1.951	2.161	2.671	1.939

	Ecology	Edu / comm	Env. science	Marine science	Zoology/ Botany	Other science
Betweenness	0.015	0.005	0.004	0.021	0.037	0.013
Clustering coefficient	0.501	0.823	0.725	0.569	0.505	0.535
Degree	21.200	17.417	14.636	22.500	22.200	19.231
Shortest path length	2.073	2.048	2.101	2.005	2.277	1.957

Figure 4 The social status indicators by gender, state/territory, and discipline for the citizen science practitioners network. The size of the nodes reflects the betweenness centrality, that is, indicating a role as a bridge to other parts of the network. Full datasets can be found in Supplemental Tables 6, 8, and 11, Appendix 4: Survey Results. State names have been shortened: ACT: Australian Capital Territory, NSW: New South Wales, QLD: Queensland, SA: South Australia, TAS: Tasmania, Vic: Victoria, WA: Western Australia, Int: International.

SHARED PRACTICE AND THE DOMAIN OF KNOWLEDGE

Practitioners dedicate time to meet with others, primarily to exchange ideas about citizen science (**Table 2**). Respondents spent an average of 4 to 8 hours per week in making and maintaining connections, and found the interactions to be beneficial. Those who committed to working together on specific projects or papers, and who had frequent and face-to-face interactions, have, on average, fewer connections and lower clustering coefficients. We surmise that because of the time and resources required to co-produce knowledge practitioners may perhaps form tighter groups. In contrast, those who indicated they work together on citizen science projects but interact less frequently and not face to face exhibited high clustering coefficients, meaning they may be more central in connecting different parts of the network.

A high number of connections is not necessarily indicative of the quality of the connections, as quality implies a level of respect, trust, and productivity that cannot be captured by numbers of connections alone. Trust develops through time and shared experiences, and can be evidenced in continuous, rather than singular, interactions with others. In our study, we used the concept of reciprocity of relationships to indicate genuine connections to others. Reciprocity is true when people identify another person they have a connection with, and in turn those people also identify a connection with them (**Figure 5**). Overall,

ELEMENTS OF SHARED PRACTICE	RESPONSES (COUNT)	AVERAGE NUMBER OF CONNECTIONS
Strength of the interaction		
Meeting up	45	13.2 ± 8.6
Email and phone contact	16	15.8 ± 15.0
Regular face-to-face work	14	8.9 ± 9.9
Nature of the interaction		
Exchange ideas about citizen science	55	15.1 ± 10.7
Work together on projects	14	8.9 ± 8.7
Write joint papers related to citizen science	6	2.7 ± 2.3
Intensity of the interaction		
Occasional	37	14.1 ± 9.4
Regular	23	11.9 ± 12.1
One-off	15	11.5 ± 11.3
Grand total	75	12.9 ± 10.6

Table 2 Number of respondents who share certain forms of shared practice, and quality of interactions. Quality is defined by the strength, nature, and intensity of the interaction.

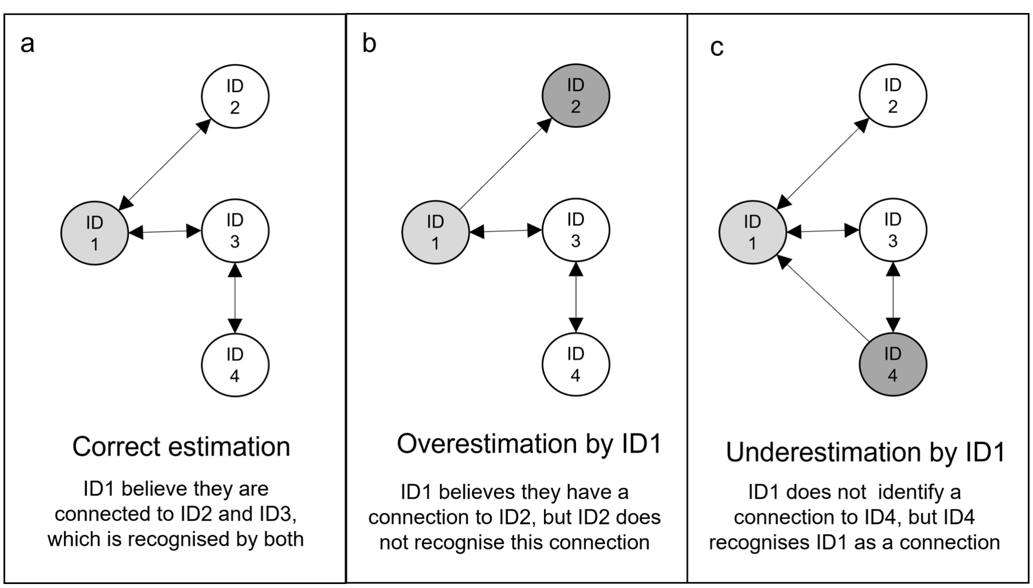


Figure 5 Schematic image of reciprocity in interactions.

only 6 out of the 75 practitioners mutually recognised each other (5a), meaning very few of the respondents correctly identified a reciprocal connection. Fifty-seven people underestimated their number of connections (5c) by an average of 5 connections, and 10 people overestimated (5b) the number of connections by an average of 6.8 connections. The tendency to over- and underestimate the number of connections was gendered (***Table 3***): women were more likely to underestimate the number of connections and by a greater margin than their male colleagues (an average underestimation of 5.6 and 3.8 connections respectively). Men were more likely than women to overestimate the number of connections they thought they had, and by a larger amount (an average overestimation of 7.7 and 2.5 connections, respectively). These results indicate interactions amongst practitioners are not yet fully reciprocal, which might be expected in a network where relationships are still forming.

The Australian citizen science practitioner network has operated primarily as a virtual network, with two national opportunities to meet amongst other occasional meetings. Practitioners who attended at least one face-to-face citizen science–related meeting were more connected than those who did not, and attendance resulted in multiple new connections (Supplemental Table 12, Appendix 4: Survey Results). For example, practitioners who attended the first national meeting made, on average, 4.4 new connections; those who attended the second national meeting averaged 7.2 new connections; and those who attended other citizen science events averaged 3.6 new connections. A total of 296 new connections (41% of all connections) were made at the second national meeting, meaning it had a disproportionately large effect on practitioners gaining new network connections. This may be due to the large number of new people available to meet. Perhaps surprisingly, regular work is also a source of connections for citizen science practitioners, even where regular work is not directly related to citizen science. More than three quarters of respondents (76%) made connections to other practitioners as part of their regular work, responsible for 36% of connections (260 out of a total of 723), with, on average, practitioners making 4.6 connections this way. This may not be completely surprising given that, at the time of the survey, most members of the Australian citizen science network were employed within natural sciences, a trend that is evident across the globe (Pecl et al. 2015; Geoghegan et al. 2016; Tancoigne 2017).

Practitioners who attended at least one face-to-face citizen science–related meeting were more likely to see benefits and opportunities for knowledge exchange and production, and less likely to see barriers to participating in the network. In particular, respondents reported that new professional relationships, formed through participating in the citizen science network, frequently developed into research or project collaborations and fostered an exchange of knowledge on citizen science practice. Benefits to the practice of citizen science included developing common methods and approaches for project delivery, for monitoring and evaluation, and for group management. Interacting with other practitioners is fundamentally a learning exercise. One respondent said, “I think it’s really important to have contact with a community of practice to hear about what worked and what didn’t. It’s a more efficient way of working and helps formulate ideas and approaches.” Comments from practitioners reflect a fruitful engagement amongst practitioners and citizen science participants, providing them with hope and a sense of purpose. Respondents advocate the worth of the network, reflected in comments such as, “I like that interacting with others in the field allows me to learn from other ways of doing things, including engaging citizens in meaningful science and finding ways to include science in the lives of those who do not have it.” Inspirationally, other respondents suggested that the community of practice was the first step in building capacity world-wide for citizen science.

Respondents did, however, note barriers to interacting with others because of distance, lack of funding to travel, or online modes of communication (Supplemental Tables 14 and 15; Supplemental Figure 2, Appendix 4: Survey Results), particularly those who were not paid for their work as citizen science practitioners. Nevertheless, respondents described ways in which barriers were being addressed such as through local citizen science practitioner chapters, online communities, and data acquisition and sharing portals. In fact, a respondent from our study suggested

GENDER	CORRECT NUMBER REPORTED	UNDERESTIMATED	OVERESTIMATED	TOTAL
Female	2 (25%)	40 (70%)	2 (20%)	44 (59%)
Male	6 (75%)	17 (30%)	8 (80%)	31 (41%)
Total	8	57	10	75

Table 3 Reporting of reciprocal relationships amongst survey respondents (number of respondents and percentage of column total in brackets).

"social media plays a much greater role at connecting us (here in Australia and with folks overseas) than your survey explores. Twitter has been an invaluable platform to make and strengthen connections with others in this field".

DISCUSSION

Our study of the Australian citizen science practitioner network has demonstrated how face-to-face meetings and participant attributes (such as age, gender, disciplinary background, and location) have influenced the growth of the network to date. The role of individual practitioners and their social network connections have also influenced the shape of the network. Social network analysis is a useful approach to examine communities of practice like the Australian citizen science practitioner network as it can make apparent how connections are made, and can identify people who perform specific functional roles. Navigating successful knowledge exchange across society and science, whether through interactions in face-to-face or virtual settings, will be a challenge as the community continues to grow in scope and size (Wenger, McDermott, and Snyder 2002; Riedy 2017; Vincent et al. 2018).

The Australian citizen science practitioner network does not have a physical home and operates primarily as a virtual network, but has clearly been shaped over time by face-to-face meetings at which participants developed new network connections. Face-to-face citizen science events were responsible for the majority of connections made across the Australian citizen science practitioner network. Those who attended had almost three times as many connections to those who did not. Even respondents who did not attend a citizen science event thought physically attending was important for building connections and sharing knowledge. Although we were unable to re-survey practitioners after a third national meeting (***Figure 1***) to confirm the significance of face-to-face meetings, increased interactions from the first two face-to-face meetings led to opportunities for knowledge exchange, and minimised barriers that might have prevented ongoing participation such as the need for time investment in maintaining connections. Face-to-face meetings are key mechanisms for facilitating interactions amongst many different types of communities (Boersma 2013; Binz-Scharf, Kalish and Paik 2015; Oester et al. 2017), and the Australian citizen science practitioner network is a case in point, in which those who attended formal national meetings were the most likely to forge new connections, to act as bridges between different parts of the network, to facilitate efficient transfers of information, and to connect previously unconnected people. Meeting hosts and participants alike, however, increasingly face ethical dilemmas such as the impact of travel on climate, justifying the cost of holding and attending face-to-face meetings or conferences (Anonymous 2010; Kircherr and Biswas 2017), and health and safety in large gatherings (e.g., such as in the case of COVID-19). Despite this, in the context of a large country with a relatively small and geographically dispersed population, benefits from investment in face-to-face meeting are evident. The development of networks (e.g. interactions between individuals and groups) has helped to facilitate information sharing, where practitioners learn from others. These networks have also played an important role in ensuring the field of citizen science continues to grow, contributing useable data, fostering science engagement, and asking important science-society questions.

Face-to-face meetings were particularly important for younger practitioners who benefitted proportionally more than their older counterparts from the interactions at those public events, and for women who made more connections. Through their network connections, younger participants accessed funding for project support and for conference attendance, allowing them to overcome typical barriers experienced by early-career professionals and by those in volunteer-based organisations (McPherson, Smith-Lovin and Cook 2001). Younger people within the practitioner network actively made connections (making them more central in the network), and indicated that exchanging innovations in practice was very important to them. Given that ideas and knowledge exchange were important benefits across the entire network of practitioners, the perspectives that younger participants bring will be essential to ongoing renewal of the network of practitioners. In fact, younger participants embraced social media communication tools, and may be able to transform the network that, to date, has favoured face-to-face meetings. Technology and virtual interactions may be able to work alongside physical, face-to-face meetings to develop relationships and collaboration in the community of practice into the future (Wiggins and Crowston 2010; Ford, Veletsianos and Resta 2014; Pan et al. 2015; Storme et al. 2016; Liberatore et al. 2018; Lundgren, Crippen, and Bex II 2020). Particularly in a post-COVID world, evaluating the effectiveness of hybrid or virtual conferences on interactions and benefits received from communities of practice will be a useful area of study. Already the Australian experience has shown it is resilient in this area, in its hybrid models of meeting up, through workplace-based and local networks and the development of online communities. However, care will be needed to ensure these clusters do not disassociate from the main networks (Shen and Cage 2015).

At the centre of the Australian practitioner network, the largest and most connected group is a gathering of frequently meeting and communicating users who shared ideas and collaborated on citizen science activities. The motivations of this group may not have been expressly described (compare with Geoghegan et al. 2016), but its characteristics (i.e., mid-career, interested in ideas and collaborations) indicate that the domain of the community appears to be tied to the desire to define citizen science practice itself, and the shared practice revolved around developing ways and means of exchanging information and ideas for facilitating this goal. In fact, the topics of the national meetings attended by our study's respondents focused on sharing, learning from one another, and exchanging ideas (***Figure 1***). As the network grows and changes, and as interactions increase amongst its various members, it could be that different components of practice or citizen science will be explored, which Wenger, McDermott, and Snyder (2002) describe as a sign of a maturing network. For example, in our study, early-career respondents wanted more from the network in the form of practices and products. To meet this need, connections between early- and mid-career practitioners could be encouraged to bridge the gaps in domain (tying practitioners to the common thread of the network), or establishing and nesting new subgroups might address specific sub-domains (i.e., creating or nesting new threads within the network). The Australian practitioner network is evolving, demonstrated by how the domain and shared practice have shifted in line with the community of practitioners. The focus of the group has also rapidly changed—from ideas to projects to collaborations—and may continue to evolve as the community addresses the gaps in their domain, and as the motivations for participating change and mature (Wenger, McDermott, and Snyder 2002).

Critically, Australian practitioners will have to work to understand the implications of a gendered network. Women in the citizen science practitioner network were more central than men, indicating the presence of at least a few pivotal female practitioners within the network who acted as bridges to other practitioners. Citizen science networks in general are predominantly female (Tancoigne 2017), as are other networks involving volunteer organisations (Smith-Lovin and Miller McPherson 1993). Although there is no specific explanation for the prevalence of women in volunteer networks per se, homogenous work groups have more frequent contact and communication, which tends to perpetuate the presence of homogeneity, in this case gender, at certain levels within the network, and promotes strong ongoing connections (Binz-Scharf, Kalish and Paik 2015). What is perhaps more concerning is the finding that women tended to underestimate their personal networks far more than men did. We are unable to speculate the reason for this, but we think it is an important consideration for communities of practice to understand the implications of this phenomenon on ongoing connections and knowledge sharing. To ensure that key women are supported, and their network connections maintained, those men who were also bridges to others in the network perhaps should step up their contributions for the benefit of the citizen science network and themselves.

Lessons from the Australian experience are likely to be broadly relevant areas of consideration for other citizen science practitioner networks, given the similar history and goals of many of the emergent communities (Gobel et al. 2016; Storksdieck et al. 2016). Since citizen science programs and goals typically extend beyond national borders, an important area of study is how interactions are initiated, maintained, and strengthened across these individual practitioner networks (McPherson, Smith-Lovin and Cook 2001; Pelacho et al. 2020). Facilitating collaboration across global practitioner networks requires boundary crossing (Huang 2017), that is, people crossing over from one community to another. Who these people are, what characteristics they hold, and what mechanisms enable boundary crossing will be interesting areas to watch. The ability for citizen science practitioners to cross science-society boundaries is of particular interest: Proponents of citizen science advocate that its methods and findings make science more useable to the public and to policy-makers (Haklay 2015; Pecl et al. 2015; Cvitanovic, McDonald, and Hobday 2016). Citizen science is seen as an opportunity to make science meaningful through its encouragement of citizens' involvement in science (Nursey-Bray, Fidelman and Owusu 2018; Iyengar and Massey 2019; Peters and Besley 2019). The citizen science practitioner network was seen by many respondents as a crucial mechanism for enabling citizen science, and all its benefits for science and society, because the network itself is a pathway between all users of science. Citizen science is transdisciplinary in that it transcends typical disciplines or modes of approaching complex societal problems (Stock and Burton 2011) by bringing together people across academia, policy, and practice to share information and learning. The Australian community of practice has an orientation that transcends narrow disciplinary approaches and makes effective connections across geographic regions, professional statuses, and age groupings. These strong features of transdisciplinarity can help to overcome some of the limitations experienced in other science-society and learning approaches (Ellwood, Crimmins and Miller-Rushing 2017; Riedy 2017). This is a promising finding for a field like citizen science that aims to bridge the biases associated with professionalization of science and the problems associated with scientific knowledge in a post-truth society.

CONCLUSIONS

Scientific enquiry increasingly relies on networks of citizen scientists to create and share knowledge and it is therefore important to determine how networks of citizen science practitioners develop and what makes them work well. The Australian citizen science practitioner network has benefited from face-to-face citizen science events to make important connections that have been leveraged to benefit other working relationships and positive outcomes, especially for early-career practitioners and women within the network. In the current changing health and safety environment (e.g. post-COVID-19) it will be important to determine how to build connections and relationships with potentially fewer opportunities for face-to-face meetings. Our study shows that to sustain future development of the network, it will also need to consider supporting several key individuals on whom the network relies to bridge interactions between individuals. This is particularly important given the diverse range and nature of interactions across the citizen science practitioner network, which goes above and beyond typical disciplinary interactions. The emergence of transdisciplinarity amongst those working in citizen science is a promising property of this learning community that is worth working strategically to maintain.

DATA ACCESSIBILITY STATEMENT

The authors confirm that the de-identified data supporting the findings of this study are available within the article and its supplementary materials.

NOTE

1 One respondent identified as neither male nor female. Because of the small sample size for this category, we were unable to use the response in our analysis of the influence of gender.

SUPPLEMENTARY FILES

The Supplementary Files for this article can be found as follows:

- **Appendix 1.** Survey Questions. DOI: *https://doi.org/10.5334/cstp.358.s1*
- **Appendix 2.** Summaries of Information on Early Development of the Australian Citizen Science Practitioners Network. DOI: *https://doi.org/10.5334/cstp.358.s2*
- **Appendix 3.** Methods Statements. DOI: *https://doi.org/10.5334/cstp.358.s3*
- **Appendix 4.** Survey Responses. DOI: *https://doi.org/10.5334/cstp.358.s4*

ETHICS AND CONSENT

This study received human ethics research approval from the University of South Australia (protocol 32853).

ACKNOWLEDGEMENTS

We wish to thank all survey respondents for their contributions to the study. We also thank the Australian Citizen Science Association's Management Committee for promoting this study in its initial stages. We extend grateful thanks to Cecilia Villanueva who assisted with preparing the manuscript. We also thank the many citizen scientists contributing to citizen science projects all around Australia. GP was supported by an ARC Future Fellowship.

FUNDING INFORMATION

We acknowledge the generous support for early citizen science meetings from the Australian Academy of Science, Inspiring Australia and the Office of the Chief Scientist. Their support provided funding and opportunities for the authors of this study to connect, leading in part to this study.

COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

All authors (CS, GP, IvP, PR) contributed to the design of the study; PR coordinated data collection; IvP, CS and GP contributed to data analysis; CS, GP and IvP drafted the manuscript, with review by PR.

AUTHOR AFFILIATIONS

Carla Sbrocchi *orcid.org/0000-0003-3841-2679*
University of Technology Sydney, AU

Gretta Pecl *orcid.org/0000-0003-0192-4339*
University of Tasmania, AU

Ingrid van Putten *orcid.org/0000-0001-8397-9768*
CSIRO, AU

Philip Roetman
University of South Australia, AU

REFERENCES

ACSA. 2016. Strategic Plan 2016–2018, *Australian Citizen Science Association*.

Albert, R and **Barabasi, AL.** 2000. Topology of evolving networks: Local events and universality. *Physical Review Letters*, 85(24): 5234–7. DOI: *https://doi.org/10.1103/PhysRevLett.85.5234*

Albert, R and **Barabási, AL.** 2002. Statistical mechanics of complex networks. *Reviews of Modern Physics*, 74: 47–97. DOI: *https://doi.org/10.1103/RevModPhys.74.47*

Anonymous. 2010. Conference calendar: Is less more? *Nature Cell Biology*, 12(8): 729. DOI: *https://doi.org/10.1038/ncb0810-729*

Barabási, AL and **Albert, R.** 1998. Emergence of scaling in random networks. *Science*, 286: 509–12. DOI: *https://doi.org/10.1126/science.286.5439.509*

Barabási, AL, Jeong, H, Néda, Z, Ravasz, NE, Schubert, A and **Vicsek, T.** 2002. Evolution of the social network of scientific collaborations. *Physica*, 311: 590–614. DOI: *https://doi.org/10.1016/S0378-4371(02)00736-7*

Binz-Scharf, MC, Kalish, Y and **Paik, L.** 2015. Making science: New generations of collaborative knowledge production. *American Behavioural Scientist*, 59(5): 531–47. DOI: *https://doi.org/10.1177/0002764214556805*

Bodin, O. 2017. Collaborative environmental governance: Achieving collective action in social-ecological systems. *Science*, 357(6352). DOI: *https://doi.org/10.1126/science.aan1114*

Bodin, Ö, Crona, B and **Ernstson, H.** 2006. Social networks in natural resource management: What is there to learn from a structural perspective? *Ecology and Society*, 11(2). DOI: *https://doi.org/10.5751/ES-01808-1102r02*

Bodin, O and **Crona, BI.** 2009. The role of social networks in natural resource governance: What relational patterns make a difference? *Global Environmental Change*, 19: 366–74. DOI: *https://doi.org/10.1016/j.gloenvcha.2009.05.002*

Bodin, O and **Prell, C.** 2011. *Social networks and natural resource management*. Cambridge: Cambridge University Press. DOI: *https://doi.org/10.1017/CBO9780511894985*

Boersma, H. 2013. Scientific conferences remain in high demand despite online alternatives. *Elsiever Connect*, 10 September 2013, Available at *https://www.elsevier.com/connect/conferences-remain-in-high-demand-despite-online-alternatives*.

Burt, R. 1992. *Structural holes: The social structure of competition*. Boston, MA: Harvard Press. DOI: *https://doi.org/10.4159/9780674029095*

Crona, B and **Bodin, Ö.** 2006. What you know is who you know? Communication patterns among resource users as a prerequisite for co-management. *Ecology and Society*, 11(2): 7–. DOI: *https://doi.org/10.5751/ES-01793-110207*

Cvitanovic, C, McDonald, J and **Hobday, AJ.** 2016. From science to action: Principles for undertaking environmental research that enables knowledge exchange and evidence-based decision-making. *Journal of Environmental Management*, 183(3): 864–74. DOI: *https://doi.org/10.1016/j.jenvman.2016.09.038*

Ellwood, ER, Crimmins, TM and **Miller-Rushing, AJ.** 2017. Citizen science and conservation: Recommendations for a rapidly moving field. *Biological Conservation*, 208: 1–4. DOI: *https://doi.org/10.1016/j.biocon.2016.10.014*

Ford, K, Veletsianos, G and **Resta, P.** 2014. The structure and characteristics of #Phdchat, and emergent online social network. *Journal of Interactive Media in Education*, 2014(1): p.Art. 8. DOI: *https://doi.org/10.5334/2014-08*

Geoghegan, H, Dyke, A, Pateman, R, West, S and **Everett, G.** 2016. *Understanding Motivations for Citizen Science*. Final report on behalf of UKEOF, University of Reading, Stockholm Environment Institute (University of York) and University of the West of England.

Gobel, C, Cappadonna, JL, Newman, GJ, Zhang, J and **Vohland, K.** 2016. Chapter 2 – More than just networking for citizen science: Examining core roles of practitioner organizations. in Ceccaroni, L and Piera, J (eds.), *Analyzing the Role of Citizen Science in Modern Research (Advances in Knowledge Acquisition, Transfer, and Management),* 24–49. USA: IGI Global. DOI: *https://doi.org/10.4018/978-1-5225-0962-2.ch002*

Haklay, M. 2015. *Citizen Science and Policy: A European Perspective*. Wilson Center Commons Lab.

Hayat, T and **Mo, GY.** 2014. Advice giving and receiving within a research network. *American Behavioral Scientist*, 59(5): 582–98. DOI: *https://doi.org/10.1177/0002764214556802*

Hecker, S, Bonney, R, Haklay, M, Hölker, F, Hofer, H, Goebel, C, Gold, M, Makuch, Z, Ponti, M, Richter, A, Robinson, L, Iglesias, JR, Owen, R, Peltola, T, Sforzi, A, Shirk, J, Vogel, J, Vohland, K, Witt, T and **Bonn, A.** 2018. Innovation in citizen science – Perspectives on science-policy advances. *Citizen Science: Theory and Practice*, 3(1): 1–14. DOI: *https://doi.org/10.5334/cstp.114*

Huang, JS. 2017. Facilitating boundary crossing for interdisciplinary research collaboration. *NCURA Magazine*, 49(6): 28–9.

Iyengar, S and **Massey, DS.** 2019. Scientific communication in a post-truth society. *Proceedings of the National Academy of Sciences*, 116(16): 7656–61. DOI: *https://doi.org/10.1073/pnas.1805868115*

Kircherr, J and **Biswas, A.** 2017. Expensive academic conferences give us old ideas and no new faces. *The Guardian (Education)*, 30 Aug 2017.

Liberatore, A, Bowkett, E, MacLeod, CJ, Spurr, E and **Longnecker, N.** 2018. Social media as a platform for a citizen science community of practice. *Citizen Science: Theory and Practice*, 3(1): 1–14. DOI: *https://doi.org/10.5334/cstp.108*

Lundgren, L, Crippen, KJ and **Bex II, RT.** 2020. Profiles in practice: Stories of paleontology within an online, scientific community. *International Journal of Science and Mathematics Education*. DOI: *https://doi.org/10.1007/s10763-020-10095-5*

Lungeanu, A and **Contractor, NS.** 2015. The effects of diversity and network ties on innovations: The emergence of a new scientific field. *American Behavioral Scientist*, 59(5): 548–64. DOI: *https://doi.org/10.1177/0002764214556804*

McPherson, M, Smith-Lovin, L and **Cook, JM.** 2001. Birds of a feather: Homophily in social networks. *Annual Review of Sociology*, 27(1): 415–44. DOI: *https://doi.org/10.1146/annurev.soc.27.1.415*

Nascimento, S, Rubio Iglesias, JM, Owen, R, Schade, S and **Shanley, L.** 2018. Citizen science for policy formulation and implementation. In Hecker, S, Haklay, M, Bowser, A, Makuch, Z, Vogel, J and Bonn, A (eds.), *Citizen Science – Innovation in Open Science, Society and Policy*, 219–40. London: UCL Press. DOI: *https://doi.org/10.2307/j.ctv550cf2.23*

Nursey-Bray, M, Fidelman, P and **Owusu, M.** 2018. Does co-management facilitate adaptive capacity in times of environmental change? Insights from fisheries in australia. *Marine Policy*, 96: 72–80. DOI: *https://doi.org/10.1016/j.marpol.2018.07.016*

Oester, S, Cigliano, JA, Hind-Ozan, EJ and **Parsons, ECM.** 2017. Why conferences matter—an illustration from the International Marine Conservation Congress. *Frontiers in Marine Science*, 4: 257. DOI: *https://doi.org/10.3389/fmars.2017.00257*

Pan, Y, Xu, Y, Wang, X, Zhang, C, Ling, H and **Lin, J.** 2015. Integrating social networking support for dyadic knowledge exchange: A study in a virtual community of practice. *Information & Management*, 52(1): 61–70. DOI: *https://doi.org/10.1016/j.im.2014.10.001*

Pecl, GT, Gillies, C, Sbrocchi, C and **Roetman, P.** 2015. Building Australia through citizen science. In Office of the Chief Scientist (ed), *Occasional Paper Series*, July 2015. Canberra: Australian Government.

Pelacho, M, Ruiz, G, Sanz, F, Tarancón, A and **Clemente-Gallardo, J.** 2020. Analysis of the evolution and collaboration networks of citizen science scientific publications. *Scientometrics*, 126(1): 225–57. DOI: *https://doi.org/10.1007/s11192-020-03724-x*

Peters, MA and **Besley, T.** 2019. Citizen science and post-normal science in a post-truth era: Democratising knowledge; socialising Responsibility. *Educational Philosophy and Theory*, 51(13): 1293–303. DOI: *https://doi.org/10.1080/00131857.2019.1577036*

Riedy, C. 2017. Seeding a new transdisciplinary community of practice. In Fam, D (ed.), *Transdisciplinary Research and Practice for Sustainability Outcomes,* 14. London, England: Routledge.

Riel, M and **Polin, L.** 2004. Online learning communities: Common ground and critical differences in designing technical environments. *Designing for Virtual Communities in the Service of Learning*, 16–50. DOI: *https://doi.org/10.1017/CBO9780511805080.006*

Sbrocchi, CD. 2014. *Evaluating the Usefulness of Citizen Science for Natural Resource Management in Marine Environments*. Unpublished Thesis (MSc). University of Technology Sydney.

Shen, C and **Cage, C.** 2015. Exodus to the real world? Assessing the impact of offline meetups on community participation and social capital. *New Media & Society*, 17(3): 394–414. DOI: *https://doi.org/10.1177/1461444813504275*

Smith-Lovin, L and **Miller McPherson, J.** 1993. You are who you know: A network approach to gender. In England, P (ed.), *Theory on Gender: Feminism on Theory*, 223–52. New York: Walter de Gruyter, Inc.

Stock, P and **Burton, RJF.** 2011. Defining terms for integrated (multi-inter-trans-disciplinary) sustainability research. *Sustainability*, 3(8): 1090–113. DOI: *https://doi.org/10.3390/su3081090*

Storksdieck, M, Shirk, JL, Cappadonna, JL, Domroese, M, Göbel, C, Haklay, M, Miller-Rushing, AJ, Roetman, P, Sbrocchi, C and **Vohland, K.** 2016. Associations for citizen science: Regional knowledge, global collaboration. *Citizen Science: Theory and Practice*, 1(2): 1–10. DOI: *https://doi.org/10.5334/cstp.55*

Storme, T, Derudder, B, Faulconbridge, J, Beaverstock, J and **Witlox, F.** 2016. Mobility and professional networks in academia: An exploration of the obligations of presence. *Mobilities*, 12(3): 405–24. DOI: *https://doi.org/10.1080/17450101.2015.1116884*

Survey Monkey. 2016. *Survey Monkey*. Available at *http://www.surveymonkey.com/*.

Tancoigne, E. 2017. *Four Things Twitter Tells Us About "Citizen Science" (and 1,000 Things It Doesn't)*, Switzerland. Available at *http://citizensciences.net/2017/01/26/4-things-twitter-tells-us-about-citizen-science/*. Viewed 26 Jan, 2017.

Vincent, K, Steynor, A, Waagsaether, K and **Cull, T.** 2018. Communities of practice: One size does not fit all. *Climate Services*, 11: 72–7. DOI: *https://doi.org/10.1016/j.cliser.2018.05.004*

Watts, DJ. 1999. Small worlds: The dynamics of networks between order and randomness. Princeton University Press. DOI: *https://doi.org/10.1515/9780691188331*

Watts, DJ and **Strogatz, SH.** 1998. Collective dynamics of 'small-world' networks. *Nature*, 393(6684): 440–2. DOI: *https://doi.org/10.1038/30918*

Wenger, E, McDermott, R and **Snyder, W.** 2002. *Cultivating communities of practice: A guide to managing knowledge.* Boston, Mass: Harvard Business School Press.

Wiggins, A and **Crowston, K.** 2010. Developing a conceptual model of virtual organisations for citizen science. *International Journal of Organisational Design and Engineering*, 1(1/2). DOI: *https://doi.org/10.1504/IJODE.2010.035191*

TO CITE THIS ARTICLE:
Sbrocchi, C, Pecl, G, van Putten, I and Roetman, P. 2022. A Citizen Science Community of Practice: Relational Patterns Contributing to Shared Practice. *Citizen Science: Theory and Practice,* 7(1): 3, pp. 1–14. DOI: *https://doi.org/10.5334/cstp.358*

Submitted: 12 August 2020 Accepted: 06 December 2021 Published: 25 January 2022

Citizen Science: Theory and Practice is a peer-reviewed open access journal published by Ubiquity Press.