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RESEARCH ARTICLE

The relational nature of citizen science

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Abstract

1. Most citizen science research inherently separates the observer (citizen science participant) from the observation (e.g. data point), placing artificial boundaries around what matters and how it comes to matter. We apply three elements of the philosophical framework of agential realism to reveal a more complex picture of how data arise within citizen science programmes, and its meaning to both the practice of science and the citizen science participant: 'intra-action' (all entities have agency and are entangled with one another); 'material becoming' (what comes to matter); and 'responsibility' (accountability for what comes to matter and what is excluded from mattering).
2. We draw on a case study of FrogID—an Australia-wide citizen science program focused on calling frogs, with over 42,000 participants and over 1 million frog records. We conducted semi-structured interviews with 30 FrogID users, completing two rounds of thematic and relational coding.
3. Our findings reveal that as a consequence of their recording behaviours, FrogID participants become increasingly entangled with the nocturnal environment, with sound and with their own self. Expanding and reciprocal relationships and experiences shape the nature and frequency of their recordings.
4. Second, meaning influences what comes to matter (i.e. what is recorded and submitted) for FrogID participants. We reveal meaning related to feedback (recognition and thus reciprocity), others (social networks and participation with family and friends) and the self (physical and mental well-being and identity formation/becoming). These different forms of meaning influenced engagement with app use.
5. Third, participants communicated responsibilities related to their involvement in citizen science, including responsibilities to create knowledge (e.g. longitudinal data collection), to conserve (e.g. actively conserving frog, formally committing areas to conservation) and to educate self and others (e.g. skills and competencies required for environmental action).
6. *Synthesis and applications*: By recognizing a more comprehensive set of intra-actions, beyond the observer and the observation, agential realism can reveal when, why and how citizen science observations are made; what observations come to matter and why; and how people can create a more just world. Agential

realism can shape how citizen science participation, retention and biodiversity data generation are founded. We propose three opportunities for citizen science programs based on these findings.

KEYWORDS
agential realism, frogs, human–nature relationship, interdisciplinary research, nature connectedness, public engagement in science, social science methods, thematic analysis

1 | INTRODUCTION

Citizen science, also referred to as community science or participatory science, is a methodology where public volunteers undertake research and collaborate with scientists to collect and classify data, improving the scientific community's capacity. It is a diverse and rapidly expanding field (Cooper et al., 2021; Johnston et al., 2023; McKinley et al., 2017), with local communities becoming increasing involved (Neset et al., 2021; Palma et al., 2022). This increase in participation, spurred on by the ongoing uptake of smartphones, has led to millions of data points being collected and recorded annually for biodiversity research. Much research has focused on how these data are generated and how to make these data most useful for improving and securing outcomes for biodiversity (e.g. Callaghan et al., 2021; Chandler et al., 2017; Theobald et al., 2015).

Previous research has highlighted varied benefits and motivations of participants contributing to citizen science projects (Peter et al., 2019), including improved physical and mental well-being (Haywood et al., 2016), increases in knowledge and behavioural change (Peter et al., 2021), improved social relations (Richter et al., 2018), a desire to contribute to conservation (Larson et al., 2020) and a desire to learn (MacPhail et al., 2020). While such studies are revealing the benefits that people can experience when participating in citizen science projects, most social science research on citizen science is quantitative research (e.g. Bowler et al., 2022; MacPhail et al., 2020; Richter et al., 2018; Santori et al., 2021), and tends to be underpinned by realist assumptions.

A realist philosophical framing, common in the classical sciences (e.g. biology, chemistry), tends to embed assumptions that people can make objective observations of their subject (e.g. bird, frog, plant; Pérez-Hämmerle et al., 2024). The human is 'agential' (i.e. one with capacity or power to fulfil a potential), conducting the science and deriving or producing benefits from it. To illustrate, upon hearing a frog, a person might walk towards it and take a photo or record that individual frog on a citizen science app, making an 'objective observation' (Figure 1.). This objective data, collected in a verifiable way, can then be added to the relevant citizen science database to create a picture of reality (i.e. the world 'out there') (see Moon & Blackman, 2014).

Yet, according to some philosophical frameworks, there is no 'objective' view of the world that is free from biases or perspectives. One such framework is agential realism, which is a philosophy that

FIGURE 1 Citizen science is often considered from an objectivist perspective, where the citizen scientist makes a recording of the subject (i.e. frog), which forms an objective data point in the citizen science database.

emphasizes the entanglement of the observer and the observed, where our knowledge is always based on our own experiences and perspectives (Barad, 2003). Here, an 'objective' view of the world that is free from biases or perspectives cannot really exist.

To illustrate, we consider, FrogID, an Australia-wide citizen science program focused on calling frogs (Rowley et al., 2019). Any single observation is complicated by different elements including the frog/s and whether or not they are vocalizing; the citizen science participant's senses and how they change over time, their motivations and sense of risk or adventure; the context (e.g. the weather, time of day/night, who they might be with and how that relationship encourages or discourages a recording); the smart phone, its charge, data connectivity; and the FrogID staff members or volunteers who validate (i.e. correctly identify) each FrogID recording and then provide feedback that could influence the likelihood of future recordings. It is the co-constitution of entities through their intra-actions (i.e. that each entity is essential to the existence of the other) that coalesce to enable, inform and create the observation itself (Barad, 2007), a process repeated across an increasing number of tech-based citizen science programs (Henfridsson et al., 2018; Sanches et al., 2022).

Our understanding and experience of the world is therefore not solely based on what we sense (e.g. see, hear, feel) but also on how we intra-act with it, and the tools we use to experience it. Within agential realism, people are not considered to be outside observers of the world but part of the world in its 'ongoing intra-activity' (Barad, 2007, p. 184). The concept of 'interaction'—a static, linear, isolated and independent process of cause-and-effect—is replaced with 'intra-action', emphasizing the dynamic, entangled and co-constructed nature of entities and their interactions (Barad, 2007; Hertz & Mancilla Garcia, 2021). Entities are always already entangled (i.e. inseparable, see Brown et al., 2020) and their identities and boundaries are constantly being co-constructed (see also Haraway, 2003). As such, the focus shifts from 'objects' and 'things', to entanglements, relationships, phenomena and reconfigurations, that is, intra-actions.

With a focus on 'citizen science', our aim is to advance the application of agential realism in the field of conservation to understand how complex intra-actions give rise to different sets of knowledge. Our work responds to calls to improve 'social–ecological' outcomes through applying relational ontologies to conservation and sustainability science (e.g. Eyster et al., 2023; Hertz & Mancilla Garcia, 2021). A relational ontology does not assume there is an observer per se but rather that all entities are responsible for the emergence of properties and relationships; people are a part of Nature, not separate or distinct entities (Gallegos-Riofrio et al., 2022; Pérez-Hämmerle et al., 2024). As such, relational ontologies are increasing in their prevalence because they permit humans and Nature to be considered as 'one' (Dunkley, 2023; Gould et al., 2023; Haraway, 2016; Kimmerer, 2013), revealing new ways of understanding these complex relationships, and, here, deepening our understanding of the entangled nature of citizen science.

We begin by outlining three valuable tenets of agential realism for understanding and exploring people-Nature, before discussing our method of interviewing 30 FrogID participants around intra-actions with/as self, community, frogs and Nature. From there, we discuss (1) the agential roles and relationships identified by participants; (2) what comes to matter as a result of these relationships; and (3) forms of responsibility and accountability. Our research offers an analytical framework and guiding questions to improve the ways in which we approach and understand conservation intra-actions, with the goal to make visible agential factors that assist in understanding the nature and complexity of material outcomes of conservation actions. We conclude by offering three broad opportunities for citizen science, and conservation more broadly, that arise from within an agential realism framing.

1.1 | Agential realism for conservation

At least three related elements of agential realism appear to be particularly valuable for biodiversity conservation, in terms of creating what comes to be known as reality and how it becomes meaningful: 'intra-action' (i.e. all entities have agency, are mutually constituted and are entangled with one another); 'material becoming' (i.e. what comes to matter); and 'responsibility' (i.e. accountability for what comes to matter and what is excluded from mattering). We discuss each of these elements in turn, using citizen science as an illustrative example throughout. We emphasize here that these elements are not discrete. Our intention in handling each of them separately is to provide space to explore these interrelated concepts of agential realism in sufficient detail to ground them for the purposes of our analysis (see also Hertz & Mancilla Garcia, 2021). Furthermore, we necessarily make 'agential cuts' (see below), whereby we use classifications and categorisations in ways that seek to make the meaning of our argument clear on the basis of common language, but necessarily obscure the entangled nature of some relations.

1.1.1 | Intra-action and entanglement

The first element assumes that entities are not isolated or independent, but are always already entangled in complex networks of relationships that produce them and shape their actions (Sencindiver, 2017). As such, agency (i.e. a capacity to act) is not considered as an 'attribute' of an entity, but rather as a doing or being, an intra-acting, an enactment (Barad, 2007). According to this assumption, we cannot solely consider just the 'observer' (i.e. the citizen science participant) and the 'observation' (i.e. the data, recording, photograph). Instead, we must consider the agential intra-actions that create specific material (re)configurings of the world (i.e. realities), challenging familiar understandings of causality (Carpentier et al., 2021; Hertz & Mancilla Garcia, 2021). To illustrate, the taking of a photograph is not necessarily a one-way interaction where the photographer is the agent and nature is the object. Rather, nature informs how the photograph is taken, in terms of how shapes influence the angle of the shot (e.g. to

capture certain aspects or textures); natural and/or artificial lighting (e.g. to put something in the spotlight or shadow); the entities of interest (e.g. what is in focus and what is not in focus); the frame (e.g. what is included in the shot, such as a canopy framing the shot, and what is excluded, such as a nearby power pole kept out of the shot); and timing (e.g. the movement or presence of certain species). The agency of more-than-humans has been found to transform not only citizen science 'data' but the citizen science participants them 'selves' (see Section 3.1; Dunkley, 2023).

For citizen science, an agential realism approach would assume that each measurement is an intra-action (Barad, 2007). Instead of asking, for example, how, why and when a citizen science participant makes an observation as a linear and unidirectional relationship, we might explore the multidirectional nature of a range of relationships: how do the senses of the participant (e.g. ability to hear, see), their behavioural tendencies (e.g. willingness to sample in the rain, at night, or familiarity with different species, the extent to which they travel around), their relationships to others (e.g. friends, family, social groups) intra-act with the nature of the environment (e.g. whether it is night time, raining, windy) to influence how observations are made, and how does each observation, in turn, shape the nature of future observations (Peralta, 2021)? Underpinning these questions would be an assumption that entities are always changing and are interrelated in ways that continually influence one another, that is, 'intertwinedness' (see Section 3; Carpentier et al., 2021; Hertz & Mancilla Garcia, 2021).

1.1.2 | Mattering and meaning

Second, and relatedly, what comes to 'matter' is assumed to arise from 'intra-action', both in terms of what arises materially (e.g. an observation) and its meaning (Barad, 2003, 2007, p. 140). In terms of citizen science, agential realism assumes that the apparatus (i.e. the person making the observation) is causally significant in what becomes 'real' (see also Dunkley, 2023). That is, citizen science participants represent boundary-making practices that make (a version of) reality and its meaning possible.

To illustrate, two different citizen science participants would 'make matter' (i.e. find meaning and thus bring into being) two entirely different realities through their use of citizen science apps. These different materialities could be based on when they wake, where they live, how they move around in their days, whether or not they are employed, how they experience the night-time or more remote locations (e.g. excited or afraid), how attuned their senses are, what is meaningful to them (e.g. rare species), how committed or capable they are in making a record of each observation or how experienced or familiar they are with technology. Importantly, agential realism does not really acknowledge a separation between the person (i.e. observer) and the 'observation'; such a separation would be considered artificial and incomplete, since the observation cannot be made or understood independently of its entanglement with the person (i.e. the apparatus) and practices of observation (Barad, 2003).

Barad (2007) labels this separation the 'agential cut', which describes the ways in which boundaries and properties of 'components' become determinant and thereby meaningful. This concept applies beyond human life worlds, permitting social–ecological inquiry of the cuts that make one 'part' of the world bounded, propertied and meaningful to another 'part' of the world (Eyster et al., 2023; Hertz & Mancilla Garcia, 2021). Crucially, the observed entity is always a product of the entangled practices and apparatuses that produce it and the arbitrary nature of the choices made in defining reality. What is important here is that as we increase our understanding of these agential cuts and intra-actions, we increase our understanding of how they contribute to the ways in which we describe and define reality, and importantly, the ways in which some things come to matter, while others do not. For citizen science, these agential cuts influence the picture of reality we create through individual data collection practices.

1.1.3 | Responsibility

Third, our intra-actions, including our agential cuts, make us responsible for what *becomes* 'real'. Objectivity, therefore, is an 'accountability for what materializes, for what comes to be', making it critical that we consider our own role in constituting who and what comes to matter (Barad, 2007, p. 361). An agential realism approach would assume that each citizen science participant is being shaped through their relationships, observations and recording activities, changing their experience of, and intra-action with, the world around them. Relationships come to be seen and experienced as reciprocal, where more-than-human entities—a term used to recognize that the non-human world has causal powers and capacities of its own (Abram, 1996; Whatmore, 2006)—practice agency in developing and (re)shaping relationships (Barlo et al., 2020). More-than-human thinking seeks to 'see beyond human rationality, dissolve binary or oppositional categories that elevate 'people' above 'nature', and recognise the agencies, and dependencies, of a range of living and non-living non-human actors including plants, animals and ecosystems' (Maller, 2021). The more relationships a person has with another entity, the more fully they can comprehend its form, deepening understanding (Wilson, 2008). If we agree with the assumption that reality is generated through continuous and reciprocal intra-actions, by extension then, we must consider the responsibilities we have to other entities and for living justly (Barad, 2007).

Responsibility is therefore critical in ensuring that respectful and reciprocal relationships form part of the ethics or morals that guide one's search for knowledge and inform what information and connections are worthy of seeking (i.e. one's axiology) (Wilson, 2008, p. 79; Barad, 2007). In other words, it is not sufficient to only seek to understand the actions of the human; attention needs to be paid to the full set of material practices involved within the phenomenon (Barad, 2007). It becomes less a matter of

seeking a neutral or unbiased representation of an external reality, and more a matter of understanding, and being accountable to, the entangled practices and apparatuses that produce knowledge of reality (Barad, 2007).

By exploring citizen science in this way, we can surmise that different entities (humans and 'more-than-humans') are active in creating not just what matters, but what becomes known as reality. For example, the spatial and temporal gaps, common to citizen science data, can map racial and socio-economic differences (Mahmoudi et al., 2022). Thus, we need to be attuned to how entities (are enabled to) participate in (re)configuring what is or will be possible (Barad, 2007, p. 33). As such, it becomes important to ask: What responsibilities do we have to other people, future generations, more-than-human species and ecosystems themselves in our knowledge practices?

2 | METHODS

2.1 | FrogID: A case to illustrate citizen science

FrogID is a national citizen science program developed and hosted by the Australian Museum aimed at engaging people across Australia to help provide scientists and land managers with valuable data for the protection and conservation of frogs (Rowley et al., 2019). FrogID uses a smartphone app where participants submit 20–60 s audio recordings of calling frogs. The app adds associated metadata (time, date, latitude, longitude and an estimate of precision of geographic location) to each submission. After a recording is submitted, one or more members of the Australian Museum's FrogID Team independently identifies any frog species heard calling in the recording. The participant then receives an app notification or email including both the species identified in the recording and a personalized note from the FrogID team member thanking them for their contribution and addressing any questions or comments they included with their submission (Figure 2). With over 42,000 participants as of August 2023, FrogID has compiled a data set of over 1 million frog records across Australia.

2.2 | Interviews

We conducted semistructured interviews of approximately 30 min with 30 FrogID users. We piloted the interview questions with two FrogID team members who were also app users. The remaining 28 participants were identified using a random sample of survey participants who had indicated interest in receiving further information (potential pool = 842) in a previous but related survey focused on quantifying motivations and behaviours of FrogID users (Thompson et al., 2023). Our recruitment pool is therefore likely to constitute an active subgroup of FrogID participants.

We conducted the interviews between March and May 2022, in the audio or video format most convenient to the participants (i.e. telephone, Zoom or Microsoft Teams). Participants provided written consent before participating in the interview by signing and emailing a PDF to the interviewer. Interview questions covered basic non-identifiable demographics (age range, gender, metro/regional/rural location), warm-up questions about how participants got involved with FrogID and their typical recording experience and questions designed to elicit responses on the themes of relationships with self, others/community, frogs and Nature (Figure 3; see Supporting Information for a copy of the interview questions). We audio recorded the interviews and created verbatim transcripts for analysis, assigning each participant a pseudonym.

Final interview and administration procedures were approved by the Human Ethics Committee at UNSW Sydney (HC211002). Informed consent was obtained from all participants.

2.3 | Analysis

We used NVivo 12 (qualitative data management software) to conduct our thematic analysis, by identifying patterns in descriptions of relationships, as well as information relating to perceived connections among themes. The initial coding structure consisted of codes relating to relationships with self, others, frogs and Nature (see Figure 3). This coding was iteratively refined through the analytical process (e.g. Braun & Clarke, 2021), adding subthemes to each of the four parent codes (e.g. relationship with self included such subthemes as well-being and identity facilitation, and relationship with others included family, recording partnerships and broader frog-loving community). While structuring interview questions and responses in this objective way yielded useful insights and anecdotes about the consequences for relationships of FrogID use, it became clear that the artificial boundaries, or reduction of the data, involved in this relationship-oriented thematic analysis denied the 'relationality' of the data itself: the inseparable intra-actions that produce citizen science (see also Dunkley, 2023). The data analysis was not revealing the depth and richness of, nor the emotion associated with, the webs of intra-actions being shared by participants. Thus, we conducted a second round of coding, employing relational themes of agential realism. In doing so, the child nodes were re-organized and re-coded under the parent nodes of: intra-action and entanglement; mattering; and responsibility (Figure 4). This approach shifted the coding framework from categorizing uni- or bidirectional relationships, to one of revealing intra-acting webs of experiences and transformations; not 'things' but 'doings' (Barad, 2007). For example, relationships with FrogID validators was re-coded to the mattering parent node to illustrate the agential nature of feedback: Feedback affects what comes to matter.

3 | RESULTS AND DISCUSSION

Here, we illustrate some examples of reciprocal relationships developed or enhanced through FrogID use, structured according to

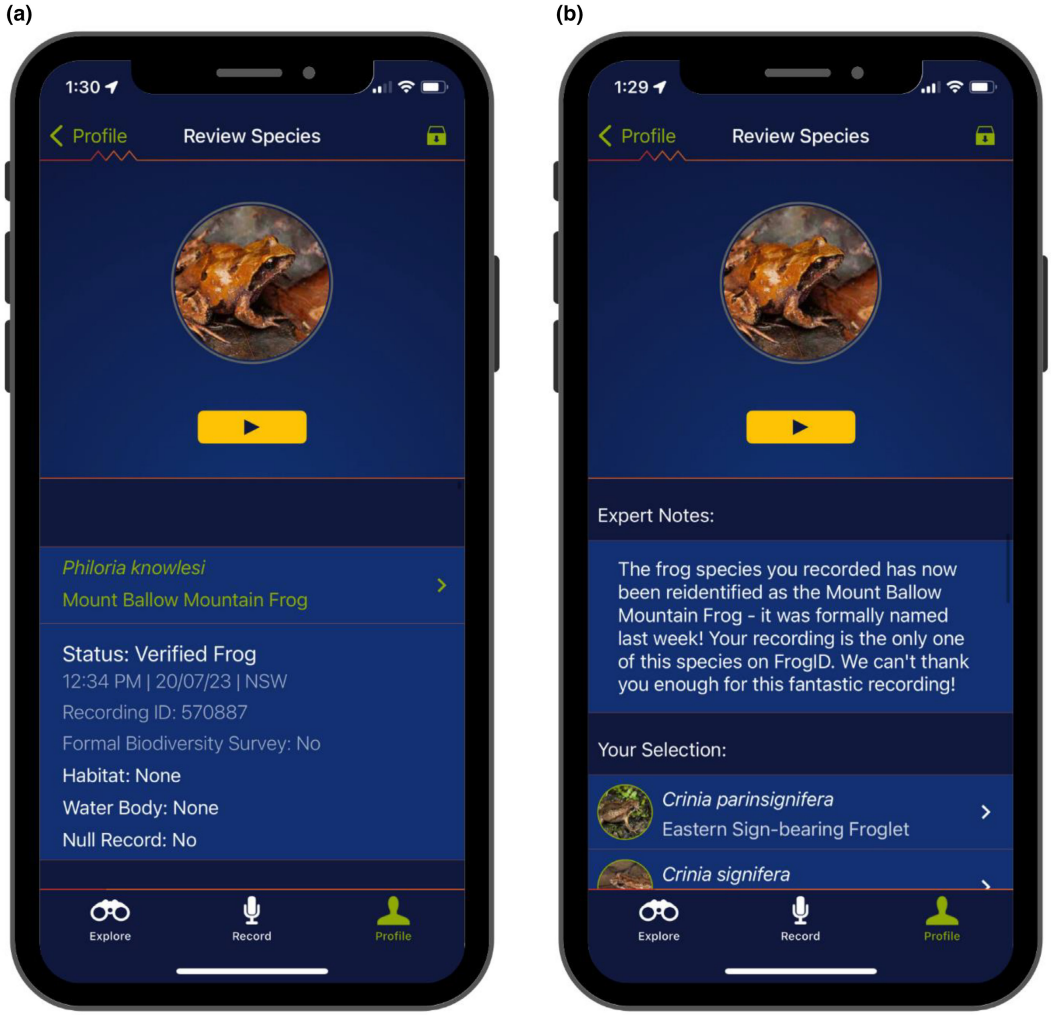

FIGURE 2 (a) Sample of FrogID app interface showing frog species verification; (b) feedback from the Australian Museum FrogID Team.

the three related elements of agential realism: agency and entanglement, what comes to matter, and responsibility (see Section 1.1; Figure 4). We reframe the traditional story of how citizen science participants' existing demographics and qualities affect their data production and behaviour (Jordan et al., 2011; Land-Zandstra et al., 2016; MacPhail et al., 2020; Nov et al., 2014) to how design materials, people and the environment intra-act with each other in ongoing, emergent and reciprocal ways. In doing so, we must acknowledge that we have enacted a series of agential cuts to temporarily stabilize the relationships for the purposes of presenting a narrative.

3.1 | Agency and entanglement

In this section, we report on the entanglement of citizen science participants' senses, their relationships and the use of FrogID in influencing how they make observations over time and how they become differentially entangled as a result. The focus here is on the agential nature of citizen science observations.

3.1.1 | Entanglement with the nocturnal environment

Our first finding reveals the ways in which participants' entanglement with the nocturnal environment changed because of their use of FrogID. This finding matters for citizen science because many animals are more active, and thus detectable at night (Figure 4). People routinely favour animals that share our circadian rhythms (Gaston, 2019), but an estimated 30% of vertebrates and 60% of invertebrates are predicted to be nocturnal (Hölker et al., 2010). Many frogs are more active and detectable at night, and 61% of all frog call recordings submitted to FrogID are recorded between sunset and sunrise (Callaghan & Rowley, 2021). In our interviews, we heard how small forays into the night-time environment could lead to a deeper curiosity and interest in the activities of nocturnal species, with implications for FrogID observations.

Abby's story is particularly illustrative. She had first become interested in frogs while living in a rural tropical environment, where 'you don't really go out at night up there, unless you've got purpose because there's mosquitoes and all the snakes come out

and stuff'. However, upon becoming curious about all the noises she heard outside after monsoon rains, she downloaded FrogID and started recording 'a certain species of frog that would call around our swimming pool and that was right by our back door'. At first all she had to do was open the door and record from her house or porch, but then noises a little further afield made her think 'okay, I'll go out the gate and I'll walk up the road a little bit', until eventually she crossed the night-time frontier and began travelling around the region recording its many species of rare frogs. 'I love going out at night now', she reflected, even though it can be 'sweaty and uncomfortable and horrible, but still like just a little magical wonderland of all of these secret little creatures that come out that you wouldn't [otherwise] see'. Through her changing relationship to the night-time environment, Abby was motivated and enabled to make recordings of frogs that would not otherwise have been 'visible' to her or the FrogID project.

Similarly, Caitlin's entanglement with astrophotography afforded her a unique opportunity to record at times when humans are not usually active in remote nocturnal environments free from light pollution: 'it's usually in the middle of bushland or forest, or up on a mountain'. She described sitting alone, 'pressing a button for hours every 20-30 seconds', and how FrogID was an activity that dovetailed with the photography and did not introduce light pollution. Rae's entanglement with frogs compelled her to engage with the nocturnal environment. She found that being out at night exposed her to nocturnal animal species and fungi, commenting 'I just wouldn't even have known that these creatures were around on my farm if I hadn't been out recording frogs and seeing them that way.'

Many nocturnal detection methods have low variance and low disturbance, and result in higher detection efficacy compared to their diurnal alternative (e.g. thermal cameras; Gaston, 2019). Implementation of new technologies has not only made nocturnal ecology possible but proliferation also highlights an opportunity to understand the value of the land at night and the way other inhabitants experience it.

3.1.2 | Entanglement with sound

Another interesting development in participants' relationships to nature involved the addition or augmentation of sensory 'layers' (Pijanowski et al., 2011). FrogID is unique among the popular biodiversity-focused citizen science apps because it relies solely on sound for species identification (Rowley et al., 2019). Some participants found it valuable to connect with nature through sound in a way they had not done previously, and others talked of an extra dimension to their experience of the natural environment. Several talked about how being present at a loud frog chorus could be an overpowering auditory experience, and used words such as singing, orchestra and music. Iris commented: 'I think it's really heightened my awareness of sounds', and Fiona felt the frog sound layer made life more interesting:

> …it gives it a kind of layer where you understand more about the environment you're in, when you can hear frog calls or bird calls. And just from hearing them, you know what animal that is, you don't have to see them or lay eyes on them, you kind of have a sense of you know, this layering of stuff, living things that are out there. And I think it makes life more interesting, to know that.

These findings indicate that some people find participating in FrogID valuable not just in relation to frogs, but in extending and developing the way they relate to aspects of the environment more generally. For example, Brooke explained how hearing a frog now made her experience of the environment 'richer':

> …it does change the experience of Nature, because it makes me think maybe that's a such and such. It likes this particular environment. So it probably gives me more awareness beyond just a species, it gives me more awareness of the environment I'm in. Maybe the habitat it's providing. …If I can hear a frog, what else can I hear? What else is here? Where did that frog fit in this system of ecology?

She reflected that these auditory cues prompted engagement with 'more than just audio and visual. It's probably the networks of Nature. The food chain, at the basic sense. But also, different synergies between species.'

It is likely that participants' intra-actions were changing as a result of becoming more attuned to sounds. With active listening practice, the brain learns to listen. Through practice, the way sound is coded in the brain changes and becomes more efficient, and subsequently, less effort is required to listen and comprehend better and faster (Pichora-Fuller et al., 2016). This finding relates to insights from agential realism that entities are always changing and already entangled, affecting the nature of what is and can be observed.

3.1.3 | Entanglement within self

A further entanglement was with personal identity and meaning. We employed a fairly common view of the self during data collection, focusing on the body, mental health and well-being, which allowed participants to describe changes in themselves in ways that made sense to them. Yet, here we also draw on ideas from relational thinking that see human beings as 'in a constant process of becoming, in interaction with the many layers of relationship in which they are embedded' (Nedelsky, 2011, p. 38). Participants talked about how using FrogID allowed them to explore, extend or regain parts of themselves they considered important and valuable, and even parts that had been lost for a period of time. The most common example was that FrogID allowed some people an opportunity to contribute

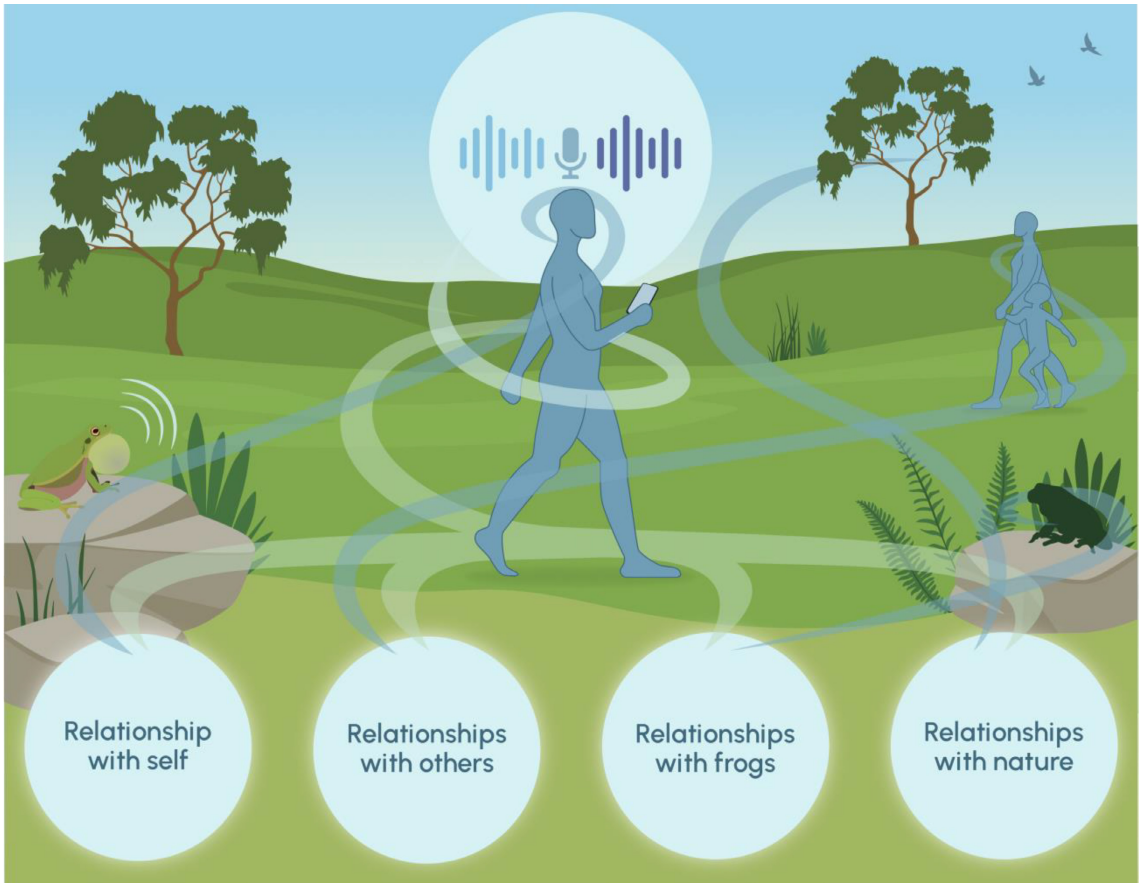

FIGURE 3 The relational framework used to guide the interviews. Shifting from an objectivist to a relational philosophical framing, we asked FrogID users about the ways in which engagement with the app had created or influenced four broad relationships: Relationships with self, with others, with frogs and with nature. We anticipated intra-actions between these relationships.

to society in circumstances of retirement or disability, and thus afforded them a way to feel useful.

> Hamish: [The best thing about FrogID is] knowing that in retirement, I can still do something that adds value, not just sitting on my arse.

Caitlin had a disability and was unable to engage in employment, but was very active in nature-focused Facebook groups. The combination of her hunger to understand 'how things fit together' in the natural world, her skills with social media and the opportunities afforded by citizen science initiatives enabled her to contribute in her own way to conservation efforts:

> Caitlin: It's lifelong struggle, it's been a long time, and I've found that doing this, it pulls me up out of that…I just feel like it's making a contribution, somehow, and it makes me feel better, because I am helping.

While many people were content to record on their own properties, for Clive, the motivation of recording frogs 'facilitates my interest or my longing to get out and about and get into quiet untrodden places'.

> Clive: I put my boots on and I put on my head torch. I'm not afraid to go off road and like, you know, really…in any direction. I'm not afraid of spiders, I'm not afraid to get covered in spiderwebs, I'll just go where I feel is necessary.

FrogID formed part of Clive's activities that facilitated his sense of being an explorer, and in turn his orienteering background and his sense of what he could contribute to the initiative, plus encouragement from volunteers when he recorded a rare frog, influenced his recording behaviour: 'And so I sort of see it as the best way I can contribute to the app by trying to find new places where the frogs have not yet been recorded'. Other instances of identity formation or reinforcement included Gabrielle, who found engaging with FrogID helped her regain a sense of herself as a problem solver; Penny, who described how FrogID helped her tap into her 'inner child' who had always loved frogs; and Abby, who had trained in evolutionary biology but did not pursue a career as a scientist. FrogID 'reignited [her] love for science' and improved her sense of confidence in scientific learning and ability to pursue further studies.

Personal outcomes reported by citizen science participants include connection to place, sense of purpose, alignment of actions and personal identity, validation from contributing, sense of self-worth from

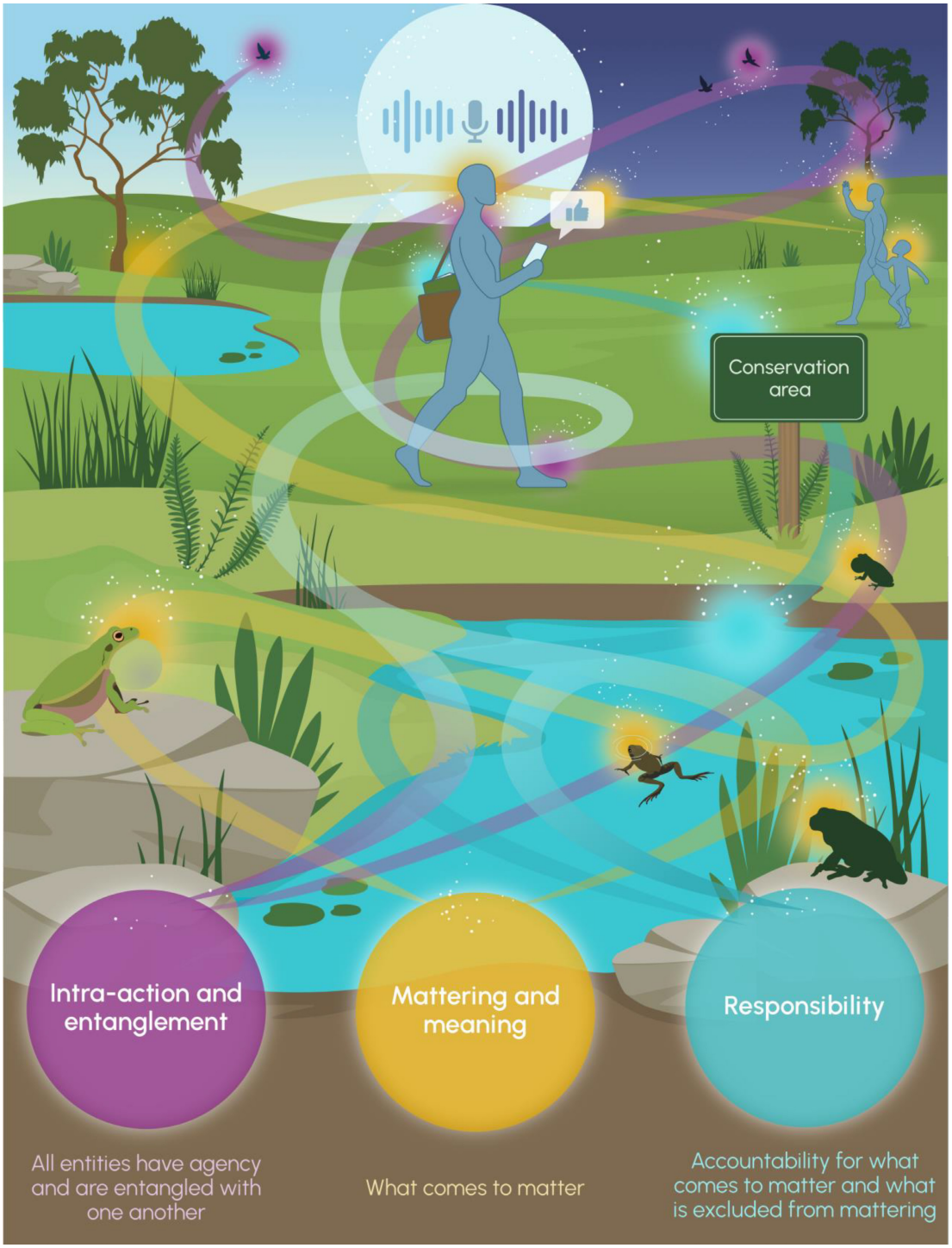

FIGURE 4 The relational nature of citizen science as revealed by the themes of intra-action and entanglement, mattering and meaning and responsibility. Intra-action and entanglement (purple) involves the FrogID participant, depicted in the centre, intra-acting with the nocturnal environment in response to frog calls; the soundscape (e.g. hearing birds, water in the landscape); and their own self and identity. Mattering and meaning (yellow) involves the transformations that occur when a participant receives positive feedback, resulting in increased recording behaviours; experiences deepen engagement with others (e.g. family and friends); and achieves an improved sense of mental and physical well-being. Responsibility (blue) manifests as a commitment to creating knowledge; to engage in formal and informal conservation behaviours; and to educate themselves and others.

positive reinforcement, shared experience of belonging and identifying with a collective purpose (Ballard et al., 2018; Bela et al., 2016; He et al., 2019; Larson et al., 2020; Pocock et al., 2023; Tiago et al., 2017). Importantly, most citizen science participants, and FrogID participants specifically, are in the second half of life (Thompson et al., 2023). This finding provides an interesting contrast to longitudinal studies of the general population that show declining scores relating to purpose in life and personal growth with ageing (Springer et al., 2011).

3.2 | Mattering

In this section, we report on how meaning influences what comes to matter for FrogID participants. Meaning arose in different ways for different participants. For some, meaning arose from their ability to share the experience of recording frogs, others found meaning in the feedback provided through the app, while others still derived meaning from the personal benefits each of their recordings provided them (Figure 4). Common among the participants were the ways in which meaning influenced how they engaged with the app and contributed to their observations—what came to matter. What struck us here was the prevalence and diversity of meaning and its influence on engagement.

3.2.1 | Others matter

While for some people recording was very much a solo activity, others found meaning in connecting with children, partners and other family members through shared FrogID experiences, which in turn affected their recording behaviour and thus what came to matter through participation. The citizen science literature has also observed varying degrees of social connection and network formation over time (Parrish et al., 2019). For some people, interactions with friends, family and like-minded people are 'overwhelmingly influential' in determining volunteer commitment, while others exhibit more of a 'loner-helper mentality' (He et al., 2019).

While many participants recorded alone, 'frogging' was often a social activity for Iris, who participated in organized frogging expeditions with members of a local Facebook group. Through these events, she was able to learn more about frog conversation, and frogging together encouraged her to put this knowledge into action:

> Iris: …and it's really good because when we do that, we do the proper hygiene stuff too, like we all wash our gumboots and all that sort of stuff. So I think it's really good for raising awareness of not spreading fungus and stuff like that.

Xanthe also pointed out that recording with other people helped her to be less 'frightened' in isolated areas where 'good' frogs are most likely to be found (see also Roper, 2016). Place-based networks of engagement and bridging interactions with those not in individuals' immediate networks are thought to be positively related to pro-social environment behaviours (Macias & Williams, 2016). For Xanthe and Iris, relationships with other people affected what came to matter in their FrogID participation.

Two participants almost always recorded in partnership with a family member. The meaning of the recording arose from using complementary skills and capacities, where one had good hearing and the other had good eyesight, or one was better with technology and the other had more interest in frogs. What matters for the purposes of making these observations visible is the entanglement of the joint observers, such that the observations might never come to matter without the simultaneous intra-action of multiple people. More broadly, it seems clear that some FrogID recordings would never come to exist without the influences of social relationships on recording behaviours.

3.2.2 | Feedback matters

FrogID also facilitated a human connection beyond the immediate family. Many participants commented on the feeling of reciprocity associated with FrogID use, facilitated by the 'human-powered' element. In other words, users were often surprised or impressed that every recording is validated by a trained volunteer or staff member who listens to the recording, determines the frog species and sends feedback to the user (often with a personalized comment). As Fiona put it, 'you're not just sending info into the abyss'. For Emily, the feedback provided when she received her first call verification made all the difference:

> Emily: …I think my turning point was that feedback. … So the app itself gives you an idea of how many species it might have been. But it's not until I got that [human validator] engagement that I really went, hey, this is an actual thing.

Interviewee Abby had started as an app user and become a volunteer and finally a staff member. She related how one of the aspects of FrogID that had first facilitated her growing interest in local frogs was the enthusiastic response she received from the person who validated her recordings. When Abby became a volunteer validator, she put the same strategies into practice, recalling how the personal touch had made her contribution as an app user feel valued. While several interviewees did not find validator comments motivating, many others appreciated this personal touch and found it encouraged them to record more often. For example, Jim talked about the excitement of recording a rare frog.

> Jim: I know it's catering to the weakness of me. I really should be satisfied to know that [the recording is] in there, then I should be satisfied to know what it was, but I'm not. I'm really satisfied when the person is taking the time to say 'nice recording Jim, thank you'.

This finding accords with literature showing that recognition of participant expertise is important for sustained engagement (De Moor et al., 2019). From these insights, it is reasonable to conclude that at least some recordings come to matter through validator feedback. Feedback has a positive effect on participant satisfaction and has been shown to improve both retention of new participants and, importantly, species identification accuracy when compared to participants who received a validated species identification but no feedback (Van der Wal et al., 2016). Furthermore, feedback is more effective when the sentiment and content are aligned with the participants' values and interests (Zhou et al., 2020). When feedback is

placed into the context of the whole initiative, the contributions of professional scientists and citizen science participants can be seen through the lens of reciprocity, with each providing something the others' needs and values. Hetland (2020, p. 274) conceives of citizen science as operating within a 'gift economy' involving 'bundles of rights and obligations for those who participate'.

3.2.3 | The self matters

We contend that the self matters in citizen science because changes to the self affect personal desires and capacities, which affect what comes to matter through changed recording behaviour. A small number of participants mentioned improvements to their physical well-being related to FrogID use, for example, sleeping better after recording or as a result of going for more walks. But a much larger number felt that participating in FrogID helped their mental well-being. Interviewees mentioned feelings of excitement, joy and relaxation related to having an excuse to indulge in a fun activity, because it also helped science; having something to look forward to as part of their day; connecting with nature; learning more about their favourite species; connecting with a wider frog-loving community; and helping with conservation efforts. For Wendy, recording frogs was her 'happy place'. Jim talked of the 'dopamine' and the 'sugar hit' of taking a good recording of a rare frog. Oliver, who was undergoing cancer treatment, talked of 'those little things you look forward to doing that makes the day a little bit more interesting, bit richer'. And Iris reported, with respect to sleep:

> Iris: So I think that you know the adrenaline plus the endorphins from exercise, and the excitement about finding out later on what it was I was recording, things like that, that all contributes to I guess physical and mental calm.

This example describes how the physical and mental effects of recording before bed can even improve sleeping, confirming findings of a systematic review that found positive relationships between greenspace exposure and better sleep quality and quantity (Shin et al., 2020).

3.3 | Responsibility

Within the philosophy of agential realism, and relational ontologies more broadly (Barlo et al., 2020; Mattijssen et al., 2020; Saxena et al., 2018), each person is considered to have a responsibility to be aware of what we are making visible, and what things we are choosing to make invisible—an 'ethics of exclusion' (Hollin et al., 2017). We need an ethics of responsibility and accountability 'not only for what we know, how we know, and what we do but, in part, for what exists' (Barad, 2007, p. 243). In this section, we report on the performative ways in which citizen science participants practice responsibility in creating knowledge, conserving and educating (Figure 4).

3.3.1 | A responsibility to create knowledge

Many participants considered their use of FrogID 'as conservation' through the provision of data that support pro-environmental action. For example, Amelia's comments indicated her understanding that what is recorded comes to matter, which contributed to her sense of responsibility to record where possible:

> Amelia: I think people feel helpless often in the face of whatever's happening on the planet. So from the standpoint of, we're retired so if we can do anything that helps, to say okay, we found this frog here, we found that frog there. …So yeah, we do feel like if you're going to be travelling around, if you hear things or see things, that by letting scientists know, if it helps at all, then yeah.

Similarly, Jim's use of multiple citizen science apps allowed him to feel like he was contributing to an intergenerational conservation effort, in the context of climate change and environmental degradation that 'drags you down':

> Jim: if you do something for FrogID or iNaturalist or eBird, I feel like I'm helping people like [FrogID scientists], either immediately or somewhere down the track, by recording what I saw or heard for someone to use today or sometime in the future. And it might not be us, it might be a generation from now. And I feel like that's a good way of adding meaning to life.

For Lucas, using FrogID was part of an explicit recognition that 'our physical being has been created from what's here on Earth, so we're connected somehow to Earth' and that humans 'should be here as guardians of this planet'. He saw FrogID as an 'opportunity to do something to put back'. Other participants reported on their role in building the 'data set' or 'knowledge base' to inform science and management (see Vallabh et al., 2016). For example, a number of FrogID participants reported developing a commitment to longitudinal data collection to assist in understanding frog behaviour.

> Dana: And what I really like about the app is at first, I thought you just record a frog. I get a banjo frog, that's the last time I ever record it. But then it became very apparent that what you actually wanted to do was follow what happened to the banjo frog all year. And I thought that was really exciting, and that taught me a lot about what they do all year.

These qualitative findings provide deeper insights into research that identified that citizen science program participants experience a sense of 'satisfaction and contribution' through their involvement (Peter et al., 2021).

3.3.2 | A responsibility to conserve

Participants reported both individual and collective actions to conserve frogs and their habitat. For example, several participants had acquired the confidence to relocate tadpoles they found in inappropriate places (e.g. on roads) and subsequently raise and release the frogs. Others created habitats in their gardens, for example by installing ponds or frog hotels, softening hard earth to create areas for burrowing frogs or even something as simple as turning over large leaves for rain to collect.

Another commonly reported change in behaviour related to use of chemicals in the household, garden or farm. For example:

> Nicola: I'm a bit more proactive in protecting the frogs…I continually ask my husband not to use sulfate of ammonia on the lawn. We don't use any chemicals anyway, but it's a definite no now. Even if we were tempted to maybe use some Roundup to kill some weeds, or- it's definitely changed how we do that.

Some FrogID participants with larger properties reported conserving areas they knew were frog habitats, for example, not cutting down certain trees or bushes (Oliver: 'you don't chop down certain things because you know the frogs live in there'), or excluding livestock from frog habitat areas.

> Iris: …we tend to leave logs around now because we know a lot of them like to use logs as shelter, so just things like that.

> Gabrielle: I've done a fair bit with [preserving frog habitats], controlling runoff, preserving ponds, culling cane toads, because when we had a severe drought here, they were eating the insects and things that the birds and other things relied on, and also goannas and other things.

As Gabrielle's quote demonstrates, actions to preserve frogs often worked to preserve other elements of the ecosystem as well. Similarly, Demi felt a responsibility to conserve her land for all the local creatures:

> Demi: We don't just own the land. We share the land with all the other animals that live here too. If we can do something to make the frogs have a good place to live, then that is a huge thing for us.

Quentin had formalized his commitment. He had entered an agreement to turn the vast majority of his 250-acre property in Queensland into a Nature Refuge, 'to make a difference to the survivability of the ecological systems here'. His primary goal was 'understanding the complexity of the ecosystems that we're trying to manage'. Doing so meant that he gave up certain property rights in pursuit of ecological conservation that would benefit both human and more-than-human communities.

Participants of citizen science programs often demonstrate strong pro-environmental norms and attitudes, and a willingness to contribute to the common good prior to their participation (Brossard et al., 2005; Crall et al., 2013).

3.3.3 | A responsibility to educate

Participants reported on the importance of developing skills and competencies to take part in environmental action, for themselves and then sharing them with others (Hadjichambis & Paraskeva-Hadjichambi, 2020). Several participants, for example, valued the opportunity FrogID provided to connect with, or educate, their children or other young relatives over a shared experience of Nature.

> Fiona: I would say the most valuable part of [FrogID], in an emotional sense, has been talking with the kids, and working with the kids, and recording with the kids, and doing things with them to help them understand what they're hearing and the environment that they're in, and to see their interest in that sort of stuff grow as well, and to see that they actually enjoy it also, and have a curiosity.

Some participants reported that the wealth of information contained within the app was enough to facilitate learning on its own. Yet, the increased interest in frogs often manifested in additional learning behaviours such as buying books, searching online for further information and watching documentaries. Some reported saying good night to frogs, talking to them or drawing them. In some instances, there was a dramatic change in knowledge and interest.

> Gabrielle: I'd say [my interest is] 100 times [bigger], from not really doing anything with frogs to now having several textbooks and magnifying glasses out, and checking them out, and finding and preserving living areas.

These experiences have also been found in experimental research that has demonstrated the ecological learning benefits of citizen science programs (e.g. Pocock et al., 2023).

4 | OPPORTUNITIES FOR CITIZEN SCIENCE PROGRAMS

Our findings illustrate the value of agential realism as a philosophical framework to understand the entanglements, relationships, phenomena and reconfigurations of the entities involved in citizen science (see also Dunkley, 2023). Such a framework provides opportunities to understand when, how and why observations are made; what observations come to matter and why; and what roles people

can and do play in creating a more just world. For example, responsibility and accountability feature strongly in this framework, as they do more broadly in understanding the behaviours of citizen science participants (Crall et al., 2013; Jordan et al., 2011; Larson et al., 2020). As such, agential realism not only assists in understanding how we shape reality through our observational intra-actions, but how those intra-actions in turn change our reality in meaningful ways. By paying attention to a more comprehensive set of intra-actions, beyond the observer and the observation, we can recognize how relational, co-constitutional entities create the phenomena of citizen science, providing opportunities to reveal emergent properties (e.g. well-being), solutions, synchronicities and transformations (e.g. respect, responsibility, reciprocity). The field of citizen science continues to expand and increasingly aims to recruit diverse participants, leading to increased pro-environmental behaviour across society. We offer three opportunities to improve citizen science program design by considering intra-actions, exploring how program design affects what comes to matter and consideration of a fuller range of responsibilities.

4.1 | Opportunity 1: Consider the diversity of intra-actions that can arise from engagement and the potential for multidimensional positive feedback

By focusing on the diversity of intra-actions entangled in citizen science engagement, opportunities exist to seek ways to deepen engagement and connection and to reconsider the ways in which we frame and describe entities and their relations. We can, for example, encourage engagement that extends a person into new places and territories (Thompson et al., 2023); improves or shapes a person's identity (Pritchard et al., 2020); and entangles a person's physical and mental well-being through deeper engagement and relationships as they participate in citizen science (Jimenez et al., 2021). Connecting approaches and findings from across disciplines (e.g. health, medicine, arts, humanities, digital innovation, cultural geography, risk psychology) has the potential to create spaces for better collaboration, inclusion and well-being from citizen science participation.

4.2 | Opportunity 2: Consider how program design can influence what, and who, comes to matter and the potential to improve social and interspecies justice

Our research has demonstrated that what comes to matter, or is excluded from mattering, in citizen science extends beyond the data itself. Focusing attention on the intra-actions that give rise to matter and meaning, or not, can provide opportunities for social justice. By failing to consider what comes to matter in citizen science, particularly in terms of program design and how it affects inclusion and exclusion (e.g. Pandya, 2012), existing biases can be further entrenched and new ones can arise (Mahmoudi et al., 2022; Pateman et al., 2021). For example, citizen science data often reveal significant temporal and spatial gaps in data availability, reflected in part by the underlying sociodemographic contexts of a particular region (Cooper et al., 2021; Schell et al., 2020). Areas with higher socioeconomic status tend to have more active participation in citizen science projects, leading to data-rich environments, whereas data from marginalized communities are underrepresented, resulting in spatial gaps (Ellis-Soto et al., 2023). As with many scientific practices, examining the 'ongoing tensions regarding the apparatuses of power that guide the research practices, researchers' thinking and ethics' within a citizen science framework is necessary (Rautio et al., 2022, p. 765).

Focusing attention on intra-actions that give rise to matter and meaning can also provide opportunities for interspecies justice. Think for a moment how people's relationships with spiders might change if an app were available to identify and understand their interesting features and habits, with a focus on the benefits they provide and the types of environments they enjoy (including a scale as to how dangerous they actually are to humans). Apps that focus on, or enable users to focus on, iconic species, such as birds, frogs and seahorses, can foreground these species as more important and/or worthy of conservation (e.g. Castejón-Silvo et al., 2023). When citizen science brings the whole of the 'lively earth' (Whatmore, 2006) into focus, it can allow humans to see *and sense* all the elements worth defending (Butler, 2020; Dunkley, 2023).

4.3 | Opportunity 3: Consider the broader responsibilities entangled in, and emergent from, the performance of citizen science

Our results, and indeed the literature more broadly, show that participants feel a responsibility (see also 'response-ability', Haraway, 2016) to contribute to scientific understanding and conservation efforts (Larson et al., 2020; Thompson et al., 2023). Agential realism, with a focus on ethics and accountability (Barad, 2003; Braidotti, 2021) is thus a good fit for understanding the experience, performance of and contributions to citizen science. Ultimately, citizen science is not fixed, demarcated or predetermined; instead it comes-to-be from intra-active agentiality that has real effects, in terms of how the nature and extent of data collected describe reality. Opportunities exist to examine how citizen science programs, including their design, are themselves agentic in forming, shaping and enabling responsibilities of participants. To illustrate, in her interconnected six-phase ecological kin-making process, Dunkley (2023) creates a sense of response-braunability by instilling within the participants a 'relational sensibility' by familiarizing them with 'river critters', increasing their awareness of the co-dependent and co-constitutive webs of human and non-human species. Participants can then enact their 'response-ability' through longitudinal monitoring and evaluation of the river's health.

5 | CONCLUSIONS

Our exploration into the dynamics of the citizen science program FrogID, through the lens of agential realism, opens up numerous

pathways for deeper engagement, social and interspecies justice, and improved conservation outcomes. Our work ultimately highlights the importance of inclusivity and diversity in program design and the emergent properties of citizen science as a tool for understanding and shaping our world. It is incumbent upon us to continue exploring these relational dynamics to foster environments where citizen science can truly thrive, contributing to a more just and connected global community, while simultaneously leveraging citizen science to advance public literacy of the natural world. Future research should seek to expand this framework, understanding when and where it can be used to advance and broaden participation in citizen science, while also testing the transferability of our findings within other geographic and cultural contexts. We encourage ongoing engagement with the philosophical framework of agential realism in realizing the multiple, intra-acting entities and benefits of citizen science.

AUTHOR CONTRIBUTIONS

Our project comprised a research team of locally based expertise across the natural and social sciences. The disciplinary diversity, combined with FrogID expertise, provided an opportunity to develop a rich study design, based on experiential knowledge. We note a lack of diversity within the interviewed sample, which largely reflects the sociodemographics of FrogID citizen science participants. Katie Moon conceived of the ideas and led the design of the research methodology. She supported the interviews and, along with Maureen Thompson, led the writing of the manuscript. Sophie Yates and Maureen Thompson, with support from Katie Moon, conceived the interview prompts. Sophie Yates led the interviews, conducted the coding and contributed significantly to the manuscript content and framing. Corey T. Callaghan secured funding, opened up a platform for exploration and served as principal investigator on the funded project. All authors contributed to revisions of the manuscript and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

The authors do not identify any conflicts of interest.

DATA AVAILABILITY STATEMENT

The data used in this research are held confidentially within a UNSW database in line with ethics requirements. It is only permitted to be accessed by authorized authors.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Supplementary Material.

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