Citizen Science in Australian Higher Education: Emerging Learning and Research Communities

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Keywords: Higher education, Australia, chemistry, botany, health, social science, citizen science

Abstract

Citizen science, though well established in Australia has not yet found wide use in tertiary science education. We offer case studies to illustrate that Citizen Science approaches are slowly being adopted and we highlight the spectrum of experiences in higher education from undergraduate to alumni. Courses that integrate citizen science methods tend to focus on the involvement of students in scientific research. More recently, however, citizen science theories and practice have been explicitly taught, empowering students to bring a critical lens to citizen science approaches in addition to contributing to scientific research. Integrative citizen science approaches can draw together research and teaching in higher education. When combined, these authentic learning experiences provide opportunities for students to practice contemporary science as part of new and emerging research frameworks. This article draws together citizen science initiatives from Australian universities. We discuss the benefits of immersive citizen science projects for learning, the potential of citizen science to connect campuses with community, and the importance of critical approaches to citizen science in a pedagogical setting. We consider ways to shape citizen science in higher education settings to broaden inclusion in science both on and beyond campuses.

Introduction

Australian citizen science has expanded rapidly in recent decades, mirroring international trends (Bonney, Phillips, Ballard, & Enck, 2016). In 2014, at a similar time to sister associations in Europe and the USA, the Australian Citizen Science Association (ACSA) was formed, representing an important step for citizen science in Australia (Storksdieck et al., 2016). While there are now more than 100,000 participants in citizen science in Australia, with ~600 projects listed on the ACSA Project Finder (ACSA, 2021a), fewer are placed within the higher education sector than elsewhere. Less than a quarter of the projects on the ACSA Project Finder originate in Australian universities (Golumbic, 2020); in contrast a 2020 survey of 125

ECSA projects found that 43% of projects originated in colleges or universities (Moczek et al., 2020), suggesting higher education is a potential growth area for citizen science in Australia. We are a group of academics across five Australian universities, each convinced of the many potential benefits of citizen science on and beyond our campuses, including opportunities for authentic and engaging learning experiences and to better connect research with the public. This paper presents case studies from each of our institutions and contexts, that traverse disciplinary settings and highlight the adaptability of citizen science at different stages of higher education - from undergraduate curricula to alumni engagement - as a tool for learning and community engagement.

While our chosen case studies are from different Australian research institutions, we present them as a potential framework to embed citizen science in universities as authentic opportunities for learning and co-creation. Our case studies span Haklay's four levels of participation in citizen science (2013) (Crowdsourcing; Distributed Intelligence; Participatory Science and Extreme Citizen Science) noting that Haklay's model builds on Arnstein's ladder of citizen participation (1969) to create a typology of participation in citizen science. At Leve1 1 'Crowdsourcing', intellectual engagement is minimal with citizens typically providing resources to support a project, volunteered computing for example. Level 2 'Distributed Intelligence' requires a greater level of cognitive contribution from participants – e.g. image classification. At Level 3 'Participatory Science', participants are involved in defining the scientific question and involved in data collection – sample collection for example with the support of scientists to analyse generated data. Finally, Level 4 'Extreme Citizen Science' describes projects that are fully collaborative, and citizen are involved with all stages of the research and even in the absence of 'professional scientists'.

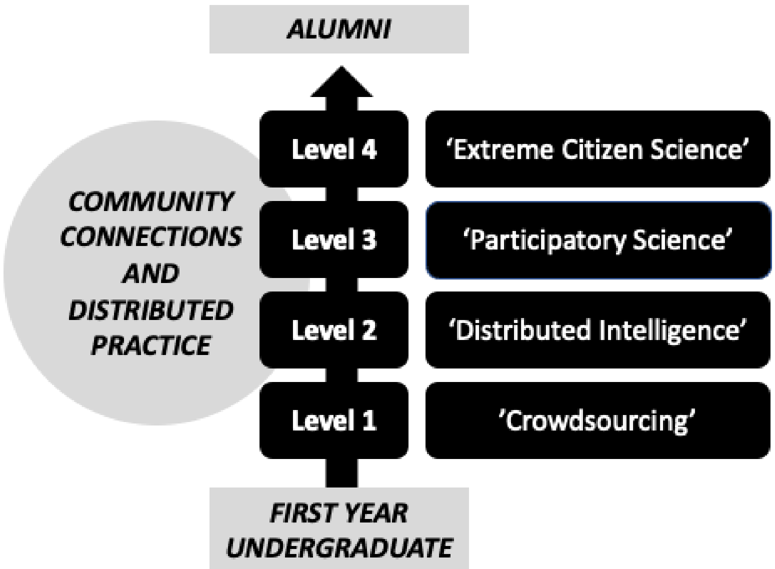

Figure 1: A possible undergraduate to alumni trajectory for citizen science participation as mapped to Haklay's typology (2013) highlighting how citizen science increases porosity between to universities institutions outside of higher education.

Citizen science has the power to increase the porosity of our institution to allow new ideas to permeate, and to allow collaboration and knowledge construction between university campuses and the broader community. By learning from experiences as 'crowdsourcing' participants in the early stages of their tertiary experience, we believe that students can be empowered to become citizens able to instigate or contribute to 'extreme citizen science' in the later stages of their study or as alumni who have been exposed to the potential of citizen science.

Our selected case studies move from early to higher years of undergraduate study, postgraduate coursework focused on critiquing citizen science methodology, postgraduate research using citizen science and alumni engagement. Together, our case studies illustrate a possible trajectory for student participation in citizen science as skills and confidence develop (Figure 1). This is not to privilege any specific level participation; the trajectory is offered for its utility aligning citizen science to the curriculum.

Case Study 1: Crowdsourcing to Distributed Intelligence: Citizen science in chemistry laboratory learning

Since 2015, a homegrown citizen science project, *Breaking Good*, has been included as part of first year chemistry teaching at the University of Sydney (breakinggoodproject.com) where undergraduates synthesise novel molecules with potential antimalarial activity (Tse, 2021; Golumbic & Motion, 2021) as part of the *Open Source Malaria* consortium (opensourcemalaria.org, Motion (nee Williamson) et al., 2016).

Labs without labs

When the COVID-19 pandemic challenged science educators to rapidly switch to teaching online (George-Williams et al., 2020), the lab-based *Breaking Good* project was no longer tenable. While colleagues developed 'dry labs' or 'kitchen chemistry' experiments that involved mailing equipment to student homes, a commitment to students' early involvement in authentic research (albeit from their homes rather than laboratories) inspired us to scaffold our laboratory teaching around another citizen science project developed by US colleagues; *Foldit* (https://fold.it/), a 'revolutionary crowdsourcing computer game' that involves folding proteins to better understand their structure and function. *Foldit* originated over a decade ago within a higher education setting and its 700,000 registered users have contributed to significant research outputs (Khatib et al., 2011; Eiben, et al., 2012; Koepnick et al., 2019).

In early 2020, the *Foldit* team released new puzzles that challenged participants to design protein structures that could bind to the spike protein of the SARS-CoV-2 virus. At The University of Sydney, a pilot lab project for advanced first-year chemistry students was established. More than 70 students participated in the Semester 1 '*Foldit* Lab', with some instantly engaged in the project challenges and others reporting steep learning curves or frustrations in their inability to obtain the 'right result' from their efforts. In common with experiences in leading authentic research experiences in *Breaking Good*, this experience highlighted the value of departure from 'recipe-style' laboratory experiments for undergraduate students. Student participation began at the level of crowdsourcing - where they performed training and game playing as instructed by the excellent tutorials embedded as part of the *Foldit* infrastructure - but over time, particularly for the most motivated students, contributions expanded to the level of 'distributed intelligence' where their cognitive ability was engaged and assessed in course assignments (Pullen et al., 2022). A similarly self-directed activity was developed for second-year chemistry students and published as an open access resource (Australian Council Deans of Science, 2021a).

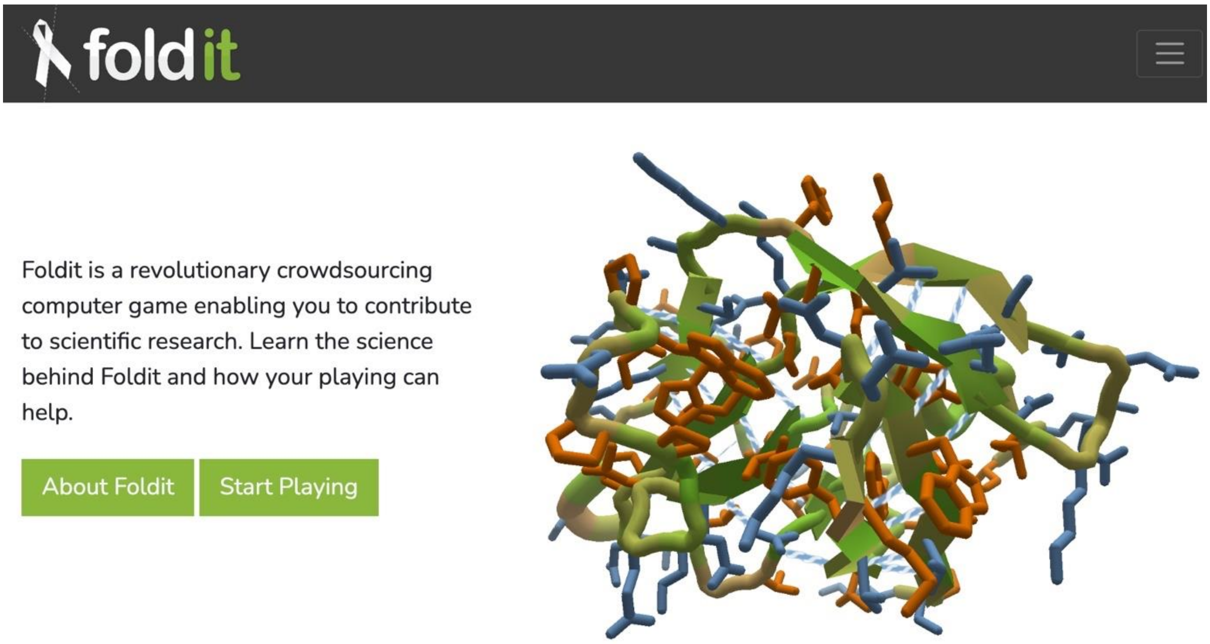

Figure 2. Foldit website. Foldit is a protein folding online game allowing players to *"contribute to advanced research on human health, cutting-edge bioengineering, and the inner workings of biology"*.

The incorporation of *Foldit* to our laboratory program in 2020 engaged students in research that demonstrated a direct link between a chemistry student's disciplinary setting and research contributing to possible solutions to the pandemic causing disruption to their lives and study. In some cases, students reported that their involvement in *Foldit* sparked conversations with friends, family, and community beyond the course, sharing their science beyond their assignments.

Learning without laboratories is a concept shared between Case Study 1 and Case Study 2, challenging traditional approaches to practical science education in universities and highlighting rich opportunities to design de novo citizen science projects for students or to integrate those designed by others for rich, relevant, and authentic learning experiences. *In case study 2 the context is now botany and project co-creators include biology students and students in other disciplines.*

Case Study 2: Participatory Science: Botanical literacy - a story of undergraduate partnerships

Plants are essential for our survival, but much to the chagrin of botany educators, plants do not capture most people's attention to the same degree as animals (Balas & Momsen, 2014). Developing botanical literacy in our science students has been a concern for close to 50 years (Mathes, 1983; Wise, 1995; Uno, 2009; Hemingway, Dahl, Haufler, & Stuess, 2011). The *CampusFlora* app (The University of Sydney, 2021) was, in part, borne out of frustration with the phenomenon of 'plant blindness' (Wandersee & Schussler, 1999) and was driven by the commitment to develop botanical literacy for the whole campus community. The project's nascent stages were in the form of a 2012 advanced undergraduate botany assignment that resulted in an online map of the locations of non-flowering vascular plants on campus. *CampusFlora* is published as an open access resource (Australian Council Deans of Science, 2021b).

The model of students-as-partners is the central philosophy of these collaborations with students (Healey, Flint, & Harrington, 2014), an approach that resonates with citizen science in that it brings those with differing levels of expertise, and from different disciplines together. In 2013 the project evolved when an academic and student team worked together to map all the trees on campus and publish the data in a co-created iOS app (Quinnell, Pettit, Pye, Pursey, & Wang, 2014). In doing so, the team transformed The University of Sydney grounds into a rich and immersive learning space primarily for botany (Pettit, Pye, Wang, & Quinnell, 2014) and engagement in participatory science, where the 'problem definition' was set by the participating students. In concert with the development of this first non-traditional research output, the team built a *CampusFlora* WebApp (campusflora.sydney.edu.au) to better manage the botanical data collected and formed a further collaboration with engineering students leading to the development of an Android version of the mobile app (Quinnell, Wang, Pettit, Cheung, & Barker, 2015; Dimon, Pettit, Cheung, & Quinnell, 2019).

The *CampusFlora* team formed new partnerships and collaborations across the university growing from roots in botany, to shoots into other disciplines, all the while seeding new opportunities for collaboration – some of which have blossomed into new projects across science and the arts (Dimon et al., 2019). In 2015, *CampusFlora* expanded into the ecology curriculum, where the citizen science project *ClimateWatch* (ClimateWatch.org.au) was being employed (Cheung, Wardle, & Quinnell, 2015). The *CampusFlora* team developed a *ClimateWatch* collection in the app (Figure 3) providing a tool to empower ecology students to improve and reinforce their plant identification skills, which in turn resulted in more accurate phenological observations in their citizen science contributions.

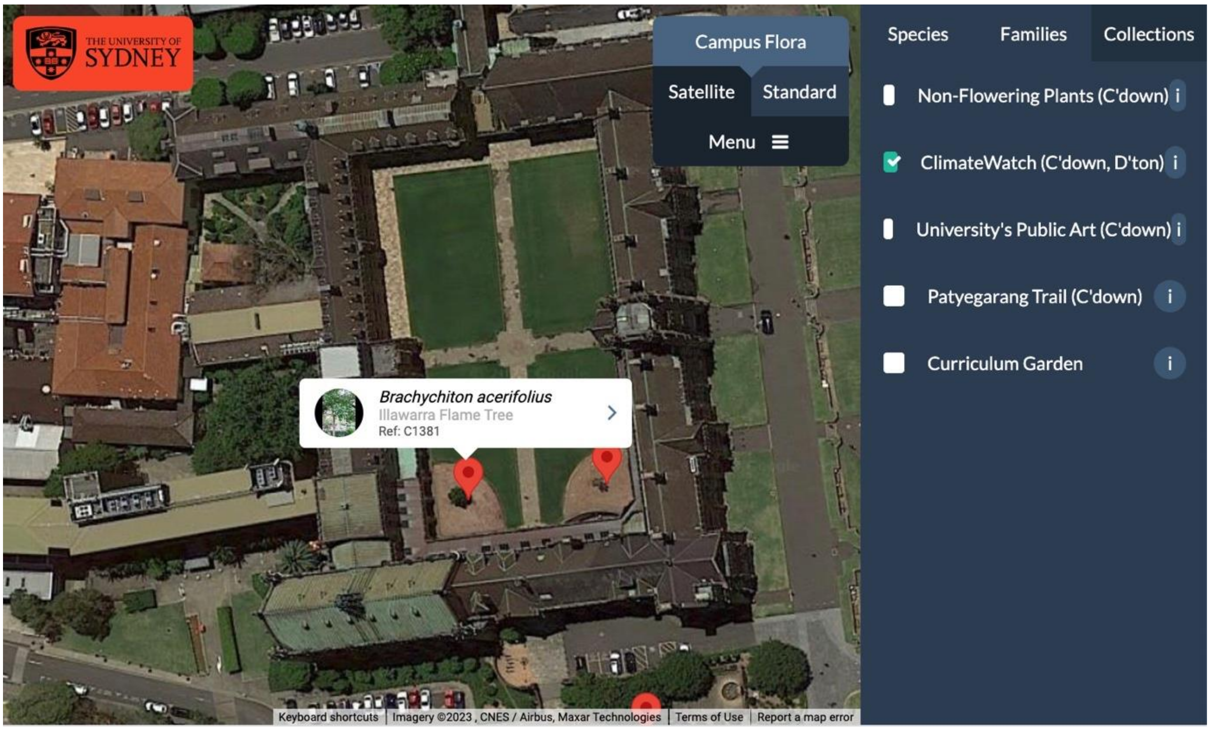

Figure 3: *ClimateWatch* 'indicator' plant species in *CampusFlora*. *ClimateWatch* is one of several themed collections offered in *CampusFlora*.

While navigating new collaborations with students, academics, and professional staff, including the Head of Grounds, *CampusFlora* emerged as more than a map to explore the locations of plants on campus; becoming a way to navigate partnerships with non-scientists and to increase cultural competency on campus. For example, to acknowledge the tradition of custodianship and law of the Country on which The University of Sydney campuses stand, we developed the Patyegarang – Sydney Language plant collection to offer the Sydney Language names for the local indigenous plants on campus (Troy, 1992; Quinnell, Troy, & Poll, 2020).

All trails (or 'collections') within the app are available to anyone who visits the campus, and this mobile technology is now a whole-of-university project, an extension of the University museum, a contributor to the sustainability strategy and a tool for citizen science more broadly. Together with student cohorts from the Faculty of Engineering, the 'OurFlora' project, enables others to create their own incidence of the app and to share their own botanical narratives in other locations. Now, by becoming a sharable app framework, OurFlora is evolving into a citizen science project with communities at other institutions and for extended collaborations with the public.

Within Case Studies 1 and 2, disciplinary learning was clearly evident in assignments designed to test this knowledge such as questions about chemical reactivity and mechanism (Breaking Good) and plant identification and cultural competence (CampusFlora). Both provide opportunities to include authentic assessments that provide opportunities for students to develop a broader understanding of science content while developing transferrable skills.

Unlike Case Studies 1 and 2 which were designed and scaffolded for undergraduate learning, Case Study 3 emerged rapidly, and from its inception was targeted at an audience that spanned those inside and outside higher education.

Case Study 3: Extreme Citizen Science: Citizen science and bushfire response

In this era of climate change, learning citizen science methods during formal education can equip students to respond to the increasingly frequent extreme weather events places including Australia will experience. Citizen science training in formal education can give students new tools to engage in active citizenship and contribute to disaster response (Calyx, 2020). Embedding this in educational experiences means that during subsequent disaster responses, people may create or contribute to citizen science for recovery with less cognitive load of new learning.

An emerging case study is that of the Environment Recovery Project, a citizen science bushfire response project created by a University of New South Wales PhD student, Casey Kirchhoff, who lost her property in the unprecedented 2020 fires (Kontominas, 2020). Kirchhoff used the open data *iNaturalist* platform to set up a project monitoring the responses and recovery of species in bushfire-affected areas, beginning with her own home (Kirchhoff et al., 2021). Established pre-disaster experience with observing plants and plant science education enabled the knowledge and capacity to launch a new citizen science project while in the process of disaster response and recovery. Nearly 400 people contributed to the project in its first year (Cornwell, Kirchhoff, & Ooi, 2021).

Citizen science is a fertile field for postgraduate research projects; emerging Australian scholars have been exploring identity in citizen science (James, 2020), its role in water management (Bonney, Murphy, Hansen, & Baldwin, 2020) and auditory approaches (Oliver, Brereton, Watson, & Roe, 2019). Recently ACSA launched a monthly early to mid-career researchers' forum, with the support of the Australian Academy of Science, involving researchers from across Australia in discussing emerging research areas (ACSA, 2021b).

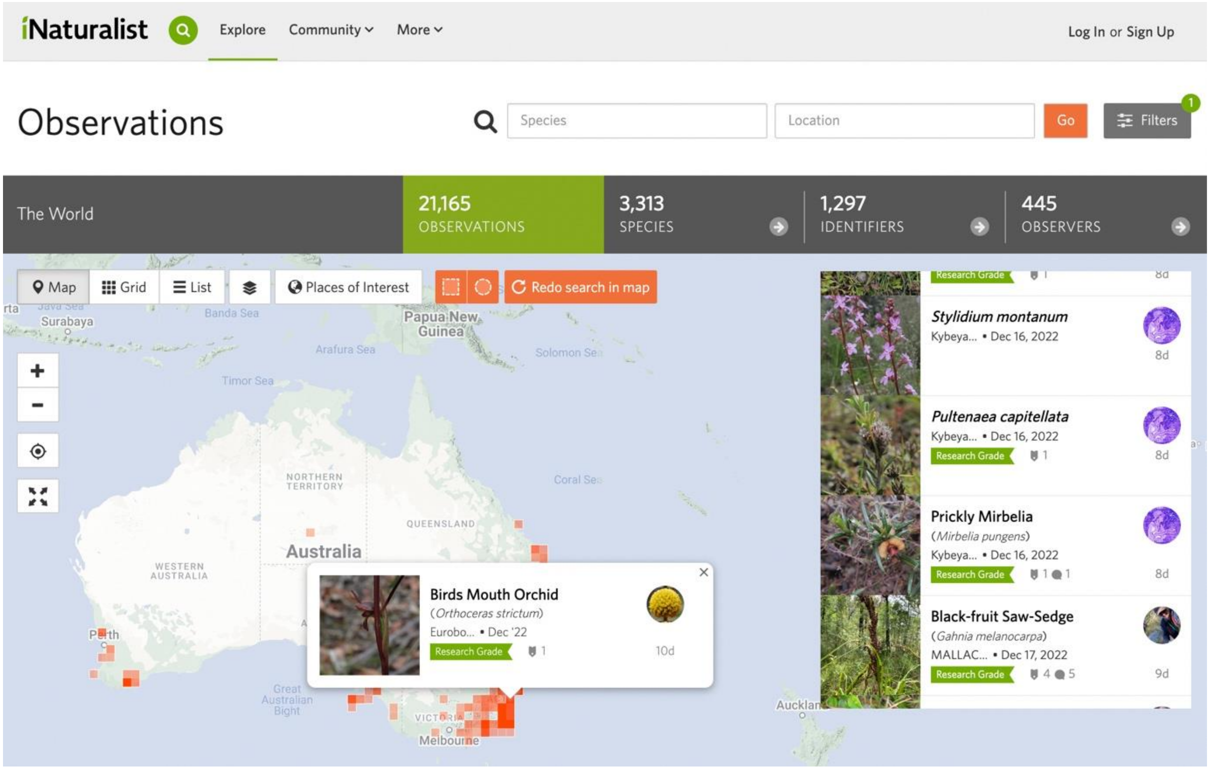

Figure 4: Environment Recovery Project, *iNaturalist* project page (2022), offering observations of post-fire recovery.

Case Study 4: Exposing typologies through the critical teaching of citizen science

While higher education institutions - including those in Australia - have a rising visibility in the application of citizen science to research, priority-setting, and education (Borda, Gray, & Downie, 2019; Mitchell et al., 2017; Wyler & Haklay, 2018), the introduction of citizen science to educational settings is not without tension. Indeed, four such tensions have been highlighted and explored (Roche et al., 2020; Kloetzer et al., 2021) with our expansions italicised - each of which we acknowledge as part of our collective experience:

1. competing *rather than complementary* scientific and educational goals
2. different underlying ontologies and epistemologies *in practices of teaching and of research*
3. diverging communication strategies *where, in many disciplines, the mode of speaking to 'experts' via peer-reviewed publications is* privileged
4. clashing values between advocacy and activism, *with consequences for participation*

Similarly, although citizen science is being used more widely in higher education, there are fewer learning opportunities that challenge the nature of citizen science projects and openly discuss tensions such as those outlined above. Courses that critically evaluate the contributions of citizen science to public engagement with science or which seek to interrogate the subject from a non-positivist mindset are also rarely part of the undergraduate or indeed postgraduate curricula.

The Master of Science Communication at the University of Western Australia (UWA) offers a unit (SCOM5309 Citizen Science) that explores citizen science from an interdisciplinary perspective, examining participation, motivations and engagement, appropriate technologies, data quality and management, intellectual property, ethical issues, and policy implications. Students begin with the concept of 'science-in-the-making' (Shapin, 1992) and its importance to public engagement with science, and then approach citizen science from both the 'science by citizens for citizens' perspective (Irwin, 1995) and the public participation in scientific research perspective (Bonney et al., 2016), thus moving explicitly through the typologies proposed in Figure 1. Students consider how citizen science projects involve citizens in their development (from design to dissemination) and critique the extent to which they can diversify (or exclude) participation in science. These aspects are essential to improving future citizen science practice, and are reflected in the learning outcomes for this unit of study:

1. evaluate citizen science projects using an understanding of common themes and key arguments in the literature;
2. plan a successful and engaging citizen science project; and
3. evaluate key tensions and issues with citizen science projects and the broader social and scientific contexts in which they sit.

These learning outcomes are assessed through tasks that emphasise the evaluation, and creation/design of citizen science projects and concepts. Students are encouraged to read widely from set texts, from key papers already mentioned such as Bonney et al. (2016), through to examples of citizen-led action such as that discussed in Kenens, Van Oudheusden, Yoshizawa, and Van Hoyweghen (2020) which, importantly, also critiques the use of the term 'citizen science' and explores it in a non-anglophone/non-Western context.

The unit was first offered in 2020 to students studying either the Master of Science Communication or the Master of Biological Sciences, some of whom had not previously studied science. Originally this unit had been designed to include several opportunities for students to get involved with ongoing citizen science projects in their local area; for example, by participating in *ClimateWatch* (Mitchell et al., 2017) and whale shark monitoring programmes (Davies, Stevens, Meekan, Struve & Rowcliffe, 2013). However, COVID-19 restrictions meant students were instead encouraged to participate in online citizen science projects such as *Old Weather* (oldweather.org; Eveleigh, Jennett, Lynn, & Cox, 2013) and *Galaxy Zoo* (Raddick et al., 2009; *Zooniverse* 2021) as a way to gain hands-on experience of participating in an active citizen science project. Feedback was overwhelmingly positive, although students suggested more interactions with people running citizen science projects would improve their experience.

Collaborations with researchers running citizen science projects in future years will both introduce the students to scientists who are actively running such projects (as raised in the above student feedback) and provide these researchers with the opportunity to critique the extent to which their citizen science projects truly develop and encourage citizen participation and agency. Creating a space in which students can actively participate in a wider range of citizen science projects will also help them to better understand the relative strengths and weaknesses of the different types of citizen science projects, and the challenges faced when developing them. Given that most of the citizen science projects that this first intake of students participated in were 'virtual' (Wiggins & Crowston, 2011), the students may not have gained a full understanding of how these projects can work in practice. However, it is clear from student discussions, work, and feedback that they were able to reflect critically on key issues such as participation and engagement within citizen science.

Case Study 5: After graduation - connecting alumni through citizen science

Despite growing literature in citizen science and Australian higher education (Borda et al., 2019), there are noticeable gaps in published case studies exploring the potential role of alumni engaging in citizen science and in understanding alumni participation in terms of applying their own disciplinary expertise or training in citizen science initiatives.

Arising from these convergences, the University of Melbourne initiated a research pilot (Science Alumni, 2020) to understand how the university can engage alumni 'citizen scientists' to better equip current and future leaders among its alumni (and potentially staff and students), with shared knowledge, skills and motivation that can aid positive societal change, in this instance through the Sustainable Development Goals (SDGs). Two aspirations are to see this initiative as a facilitator for citizen science mentorship and education opportunities between alumni and students, and to inspire future contributions to SDGs.

The first stage comprised a scoping survey (Nov 2020–Feb 2021) to identify citizen science projects linked to the SDGs among the alumni network and to quantify changes in alumni perspectives on the SDGs and measure impacts generated through these projects.

Participants described their citizen science activity with options for contributing to a peer network of alumni citizen scientists. Of the 178 survey respondents, the majority were graduates in a science or technology discipline (other specific demographics were not requested). Responses revealed alumni citizen science projects are wide-ranging in participation and scale, many encompassing local action partnerships in areas such as agroforestry, conservation, water management, sustainable buildings, and renewable energy with some alumni contributors to existing citizen science platforms, e.g., *ClimateWatch* and Bird Life Australia. Building community connections and raising awareness of SDGs through targeted actions were threaded in over half of the descriptions as a motivation for participating in a citizen science project.

In the current phase, the project will pilot a student mentorship model with campus partnerships supporting alumni involvement in mentoring panels, for example. A supporting white paper has also been presented to Faculty executives which further explores citizen science as a strategic vehicle for teaching, research, engagement in a whole of organization framework.

Discussion

The presented case studies, while not taught chronologically to one cohort of students at one institution, represent a scaffold for the inclusion of citizen science throughout the learning trajectory of higher education. Citizen science affords expansive potential for transdisciplinary collaborations that transcend the limitations of the traditional curriculum and the exclusivity of university settings. Importantly, as highlighted by Wyler and Haklay, '*the involvement of lay people challenges established ways of doing academic research as well as the self-image of universities and their role*' (2018, p.169). It is our hope that by engaging students in citizen science while openly recognising the importance of continued community inclusion we can move beyond the 'homophily' of citizen science described by Cooper et al. where '*the overwhelming majority of participants...are similar in many respects to those overrepresented* *in the science professions*' (2021, p.1386). Indeed, by increasing partnerships and collaborations between students (current and former) from different disciplinary contexts (e.g., scientists, social scientists, law, arts etc.) and the community, it might be possible to widen participation in *both* formal science education and research and citizen science.

Our case studies span Haklay's model of participation (2013) and expand into the teaching of citizen science methodologies and critiques (Figure 1). Together, they demonstrate ways for academics new to citizen science to scaffold existing projects within their teaching and assessment, through to the design and implementation of new projects as part of research and teaching. Importantly, the case studies present opportunities to learn skills that expand beyond disciplinary learning and highlight the potential for a continuum of practice in citizen science within a degree program if universities offered citizen science opportunities at all stages of scholarship.

Although nearly all projects framed as citizen science promote the broadest possible participation in theory, when it comes to practice, technical and systemic barriers mean it is easier for some to participate than others. When including citizen science in higher educational settings, we must be mindful of accessibility and inclusion for students and the broader community. For example, our case studies have shown that citizen science can allow education to continue outside of the formal classroom and despite social distancing. But while these methods might prove beneficial for some students, others will face additional challenges. Choosing to use citizen science projects that reflect universal design principles can mitigate these risks (Rose, Harbour, Johnston, Daley, & Abarbanell, 2006) as subtle design differences can change motivations to participate (Spiers et al., 2018) and lessen risks of exclusion.

Citizen science offers structures and mechanisms for engagement across and between institutions, and for direct engagement with communities. Efforts to better connect with communities has alignment with improving participation in tertiary education for historically excluded people in that both rely on making access points into university more porous. In Australia, increasing higher education porosity has a strong focus on relationship building with Aboriginal and Torres Strait Islander communities (Universities Australia, 2011, 2022). Implicit is acknowledging Aboriginal and Torres Strait Islander peoples as the Traditional Custodians of the lands where we teach and learn. For citizen science in Australian education there are implications with respect to how data is collected and used. Students and educators have a responsibility to follow protocols for ethical data collection (Walter, Lovett, Bodkin-Andrews, & Lee, 2018; Lovett et al., 2019; Carroll et al., 2020) and to work with the consent of local people as required. Exploring the implications of this with students makes for authentic learning experiences for students and educators alike.

With careful project and curriculum design, citizen science can offer a framework for learning that strengthens disciplinary knowledge but also expands beyond learning outcomes limited to scientific concepts. We invite colleagues to join us in discussions of these issues more broadly, especially the importance of effective partnerships and collaborations as key to improving practice. We also aim to strengthen collaborations between researchers who are actively involved in citizen science projects and encourage them to share this in their teaching, so that they can be of benefit to both students and the wider research culture. Ultimately, we hope that other higher education institutes who teach citizen science consider embedding elements that critique the nature of the discipline, so that students and researchers learn about its challenges and barriers to participation alongside its potential benefits to the scientific community.

Conclusion

We believe that citizen science has a valuable place in Australian universities. Through experiences with undergraduate and postgraduate students, and alumni that span participation in new or existing citizen science projects and critical interrogation of citizen science, we have observed ready engagement of our students and rich opportunities for authentic learning and community building through citizen science on and beyond our campuses.

Acknowledgements

We acknowledge and pay respect to the traditional owners and custodians of the lands on which we research, teach, and collaborate: the Gadigal people of the Eora Nation (University of NSW & Sydney), the Bedegal people (UNSW), the Kaurna people (Flinders University), the Wurundjeri people of the Kulin Nation (University of Melbourne), the Whadjuk people of the Noongar Nation (University of Western Australia).

Additionally, we gratefully acknowledge the colleagues with whom we have implemented the citizen science programs outlined in this manuscript, the students with whom we have partnered in these endeavours, volunteers who have contributed to projects and the project teams who have developed the citizen science projects that we have used in our lectures and laboratories.

Conflict of Interest

Alice Motion is the host representative on the Australian Citizen Science Association's Management Committee and Cobi Calyx was previously an elected member of the same committee.

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