CITIZEN SCIENCE:
THEORY AND PRACTICE

X-Polli:Nation: Contributing Towards Sustainable Development Goals Through School-Based Pollinator Citizen Science

COLLECTION:
CONTRIBUTIONS OF CITIZEN SCIENCE TO THE UN SDGS

CASE STUDIES

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ABSTRACT

As the citizen science (CS) community flourishes, there is an opportunity to reflect on how practitioners can widen participation and work with participants as co-researchers to investigate and take action around global challenges. Through the lens of one CS case study, the X-Polli:Nation project, we report on how technologists, ecologists, and education specialists repurposed older projects by cross-pollinating ideas with children and teachers in the UK and in Italy to create Artificial Intelligence–enhanced tools appropriate for teaching sustainability in schools. Taking part in an actionable CS cycle, children learn about pollinating insects, record scientific data, create flowering habitats, and communicate their importance. Through this process, X-Polli:Nation demonstrates relevance across a number of Sustainable Development Goals (e.g., SDG 4, Quality Education; SDG 10, Reducing Inequality; and SDG 15, Life on Land), and applies the underlying SDG principle "leave no one behind." We go on to investigate if, and how, young people would like to deepen their engagement with the SDGs, and we report that taking action and communicating the importance of the SDGs were of paramount interest. The challenge of building sustainability into an already crowded curriculum can be alleviated by understanding its value, considering the audience, and adapting to new contexts. The considerable benefits include raising awareness about global sustainability issues and giving children the confidence to become passionate environmental stewards, all the while extending the life of older projects and thus making CS methods sustainable too.

KEYWORDS:
actionable citizen science; Sustainable Development Goals; pollination; school education; co-design; international collaboration

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INTRODUCTION

As the number of citizen science (CS) projects rapidly increase (Kullenberg and Kasperowski 2016), and new theories further develop the science of CS (Vohland et al. 2021), scientists and practitioners need to reflect upon how to widen and retain participation and encourage science learning and action around sustainability, while continuing to produce data of value.

Citizen science is a term encompassing a wide range of approaches and modalities for public participation in scientific endeavours (Haywood and Besley 2014; Heigl et al. 2019). While voluntary data collection has been around for centuries, and the term itself dates to the mid-1990s (Irwin 1995; Bonney 1996), CS has gained renewed attention in recent years because of the opportunities arising from citizens' improved access to digital technologies for data recording, sharing, and verification (Dillon, Stevenson, and Wals 2016).

This new age has opened opportunities for scaling up existing projects, while at the same time repositioning CS from a largely voluntary scientific endeavour reserved for a select few, to a tool for monitoring process and engendering action, en mass, in the pursuit of global sustainability agendas (Fraisl et al. 2020).

Such a change brings forth a number of challenges, which are both practical and conceptual. If on the one hand, CS aided by digital tools may contribute to building larger data sets, on the other, it multiplies audiences and participants, who may not have had prior involvement in, or motivation to engage with, CS or sustainability issues. Conceptually, CS methods for large-scale data collection may also risk limiting and constraining the types of scientific contributions and inquiries citizens can make, often reducing them to data recorders. Here, we contribute to larger discussions on the potential of CS to promote wider and deeper participation by examining the impact of X-Polli:Nation, a CS project which focussed on young people as the primary actors for change. Bringing together the different dimensions of CS, we show how involvement of young people—in and through education—can leverage participation and support progress on the Sustainable Development Goals (SDGs).

OPPORTUNITIES FOR CITIZEN SCIENCE TO CONTRIBUTE TO SUSTAINABLE DEVELOPMENT GOALS

The Agenda for Sustainable Development (United Nations General Assembly 2015) provides a framework for "peace and prosperity for people and the planet, now and into the future." Central to this are the SDGs, which all 193 member states are committed to achieve by 2030. The SDGs include 17 goals (cross-cutting topics), 169 targets (approaches to address a goal) and currently more than 230 unique indicators (by which progress on targets is measured).

However, a recent literature review reported a lack of broader societal awareness of the SDGs, resulting in "little knowledge of the goals and how people can contribute towards achieving them" (Cowell et al. 2022, 3). One of the first publications to address how CS could support the SDGs (West and Pateman 2017) postulated that it could make contributions in three areas: 1) defining national and subnational targets, 2) monitoring progress, and 3) implementing action. As reported by a recent account by Fraisl et al. (2020), only a handful of existing CS projects directly contribute to indicators (one being, for example, SDG 15.1.2, the proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas), while all SDGs have at least one indicator that CS could contribute to (76 in total, i.e., 33% of indicators). This suggests a certain tension between CS philosophies and the framework of the SDGs. CS approaches favour democratising scientific knowledge construction over the more top-down and prescriptive nature of the SDGs. To this regard, Ballerini and Bergh (2021) raise the question of how to reconcile a global agenda with the local contexts that citizens care about, challenging the assumption that CS practitioners wish to contribute to SDGs, and whether SDGs should fall within CS aims.

Dilemmas also arise when considering the differential requirements, needs, and capabilities of different countries and communities to collect and manage large datasets. It is widely acknowledged that participation in CS is typically restricted to a few privileged demographics, raising concerns about representativeness of data and "whether individual, societal, and environmental benefits are evenly distributed" (Pateman, Dyke, and West 2021). This problem is compounded by the common challenge of "securing both project longevity and volunteer participation over the long term" (Gupta, Slawson, and Moffat 2022). Progress on targets of the SDGs needs to be reported over long time periods, yet CS project funding is often short-lived, and volunteer engagement over the long term can be difficult (Cowell et al. 2022). Crucially, this means that there is still a significant gap between the potential for CS to expand and improve the monitoring apparatus for measuring progress on SDGs, for example by including wider geographical areas, and CS capacity to catalyse the involvement of diverse communities in taking action towards global sustainability issues.

Lämmerhirt et al. (2018) suggests that there is power in creating new kinds of relationships between governments and civil society. For example, engaging young people in science outreach and connecting more effectively with

formal and informal educational settings can help with making CS and the SDGs a part of the general culture. But this requires a shift from understanding young citizens as contributors to science and policy discussions, to addressing the core meaning of collaboration (Head 2003). If contributory CS projects go beyond functional involvement in pre-designed tasks, they can be designed to help overcome barriers to young people's participation. Some of these barriers may be hidden and quite unexpected (Severcan 2015), for example when a project seeks to involve young people from disadvantaged communities, with different levels of digital access (Colucci-Gray 2022), and/or with different levels of digital and scientific literacy (van Haeften et al. 2021). Hence, building design flexibility is a way to enhance participation from diverse groups (Dupret and Chimirri 2018). Furthermore, deeper collaboration also means to proactively design a project that allows young people time to question, discuss, or develop the materials they work with (Hargreaves 1992) by contributing their own perspective on what matters (Spinuzzi 2005).

The dilemmas of CS and the SDGs are thus reframed from a purely data-driven exercise (filling an evidence gap), to an opportunity of participation in and for education. It brings into focus how CS can act as a leverage point to promote engagement and action around sustainability issues.

Here, we narrate the process by which we developed X-Polli:Nation, an actionable CS project co-designed with schools to involve school children in biodiversity monitoring and learning and in action around environmental sustainability. We then discuss the successes in developing this CS methodology for its use in primary and secondary schools. We highlight how it both raises awareness and supports action, especially towards SDGs 4, 10, and 15 on quality education, reducing inequality and life on land by:

- supporting teaching about ecological sustainability through science learning around pollination,
- providing equitable access to nature and science learning through formal schooling,
- feeding into national level biodiversity data collection initiatives,
- creating habitat in otherwise barren spaces, and
- building a cohort of informed and passionate young pollinator advocates and champions.

ENGAGING YOUNG PEOPLE IS KEY TO LONG-TERM SUCCESS

"The UN recognizes young people as rights-holders, and promotes and facilitates transparency, accountability, and responsiveness from governments, international organizations and others toward young people." This, however, does not appear to have filtered down to all national governments. For example, in England, there is not yet any mention of the SDGs, or indeed sustainability, in the Primary or Secondary National Curriculum. Also, in contexts such as Scotland, where sustainability is recognised in policy (Christie et al. 2019), teachers find it challenging to balance conflicting priorities of teaching and assessment of specific subjects versus the broader capacities of collaboration and participation (Colucci-Gray 2022).

However, school-based CS has been identified as a means for improving science education standards a decade ago (Trautmann et al. 2012), with proven benefits to pupils via increased motivation to learn science in real contexts (Kelemen-Finan, Scheuch, and Winter 2018) and development of compassionate attitudes towards nature (Hofstein, Eilks, and Bybee 2011). A review of secondary data on the US SciStarter platform (Ciasullo, Manna, and Palumbo 2019), and a long-term neuroscience CS project in Catalonia, Spain, (Ruiz-Mallén et al. 2016) showed that the real contribution of CS lies with the enhancement of the relationship between teachers and pupils, engaging them together in a co-creating partnership intended to address real scientific issues at school. Examples of CS projects involving primary school children testify to the importance of involving children in sustainable actions and behaviours at a young age, by stimulating pupils to work collaboratively with peers and their teachers to find positive and creative solutions to topics and problems that are relatable to them in their own communities (Merzagora and Jenkins 2013).

Departing quite significantly from conventional environmental education practice, designed to change behaviours, CS has been distinctly conceptualised as a value co-creation activity, aiming to establish a social ecosystem of interdependent actors, which enhances their ability to produce meaningful knowledge (Meynhardt, Chandler, and Strathoff 2016). This is particularly important in the face of climate emergencies, biodiversity crises, and widening inequalities, as such challenges will be faced by future generations and will particularly apply to the pursuit of the SDGs.

This article contributes to the growing discussion on CS and monitoring progress towards SDGs by (a) illustrating the importance of close collaboration between academics from different disciplines, education practitioners, and young people in co-designing tools for CS and (b) illustrating the value of CS as a cultural lever for changing the discourse in education from curriculum delivery to addressing together the big questions faced by humankind at this time (Dillon, Stevenson, and Wals 2016). By re-directing attention in education towards young people's participation, we argue that CS can not only play a significant role in raising awareness about the SDGs' framework but also in monitoring progress and taking action towards the SDGs, thus helping to reshape the agenda and targets themselves (Spinuzzi 2005; West and Pateman 2017).

DESIGNING THE X-POLLI:NATION CITIZEN SCIENCE PROJECT

X-Polli:Nation (xpollination.org) was set up to cross-pollinate ideas, methods, and technologies for pollinator citizen science and adapt them for use by schools. Through a process of co-design that included academics from different disciplines, national biological recording schemes, school children, and teachers, we brought together existing CS tools designed for adults to record pollinating insects, and we created a methodology for actionable CS. These existing tools included pollinator CS surveys such as Polli:Nation, species identification platforms such as BeeWatch, Italian adaptations such as Polli:Bright, and others. Rather than reinventing the wheel, amalgamating in this way enabled us to rapidly and efficiently draw together a holistic package of resources, which were already trialled and tested for their basic function and ready to be adapted for different audiences and uses. X-Polli:Nation also functions as a hub with an accompanying flexible package of educational resources for linking school children (students), teachers, education professionals, and academics from different disciplines across the UK, Italy, and further afield.

X-Polli:Nation was designed as a cycle of actionable CS (Figure 1), supported by a package of free tools and resources for children first to learn about pollinators, including how to distinguish them to species level (Siddharthan et al. 2016; van der Wal et al. 2016) and to understand their feeding behaviours (Wibowo et al. 2017); then to record data about them for science (Anderson et al. 2020), and to take action by creating habitat and campaigning for them. A key design feature of X-Polli:Nation is that it supports multiple learning journeys. Schools and students could choose to engage with any or all of the four steps of the CS cycle (cf. Figure 1) and determine the extent of their involvement. The project used the topic of pollination, already part of the curriculum, as a means to engage children with ecological processes, sustainability issues, and the global challenges of today.

Participants were recruited through our partner organisations, Learning through Landscapes (UK) and Natural History Museum Maremma (Italy), both outdoor education specialists. On the South Coast of England, mainstream primary and secondary schools were recruited, as well as those that specialised in supporting students with complex social and emotional skills (10 in total); and in Italy mainstream kindergarten, primary,

Figure 1 The X-Polli:Nation citizen science cycle (*middle*) with illustrative photographs taken in a participating school.

and secondary schools (51 in total) were supported. In both countries, there was a mixture of schools involved in earlier projects (e.g., Polli:Nation and Polli:Bright) and those new to the materials. Participants were reached through the xpollination.org website, social media, and local recruitment activities (carried out by botanic gardens in Italy and Learning through Landscapes in the UK).

POLLINATOR CITIZEN SCIENCE AS A MEANS TO TEACH ABOUT SUSTAINABILITY

Reported declines of insect pollinators poses genuine questions for both scientists and citizens (Dicks et al. 2021; Gill et al. 2016) owing to their key role in food security (Klein et al. 2007; Woodcock et al. 2019) and plant health (Ollerton 2021). Pollination is already a central topic in the science curriculum. Moreover, it is amenable to study in school grounds. This enabled hands-on action to safeguard pollinators, and X-Polli:Nation quickly expanded to creating pollinator-friendly habitats and recording data in school grounds. Schools were introduced to sustainability issues through pollinators, as the project taught about biological relationships and processes and human impacts on these, and further enabled and encouraged students to create their own inquiries around nature.

The theme of Pollination allows for a discussion of a range of interconnected global goals. A United Nations page devoted to bees suggests that by acting as pollinators, bees promote biodiversity (SDG 15), fight hunger (SDG 2), and provide decent jobs (SDG 8) in agriculture and other sectors, all contributing to the elimination of poverty (SDG 1). They maintain balance in our ecosystems, but these free service providers are under pressure from a variety of forces. Indeed, Patel et al. (2021) suggest that beyond these specific SDGs, the centrality of pollinators in supporting the ecological web is such that bees (as one of the most important insect pollinators) potentially contribute towards 15 of the 17 SDGs and a minimum of 30 SDG targets. Pollinators are thus a particularly useful way to understand the potential for CS to address the SDGs because they constitute targets that are relevant globally as well as to specific locales, thus bridging local and global concerns with everyday practical actions.

CO-DESIGNING TOOLS FOR USE IN SCHOOLS

The core of X-Polli:Nation is a CS survey enabling students to collect vital data about pollinator species groups (e.g., butterflies, bumblebees, beetles) and their feeding preferences in the same format as that submitted by adults to national schemes, but using field guides, tools, and forms designed for a younger audience. Following standard protocols for biological recording, students mark a 50 × 50 cm quadrant in a flowering patch and record the numbers of insects from each group that visit during a 10-minute period. For recording data on pollinators, we liaised with European and UK Pollinator Monitoring Schemes and made use of the facilities provided by the Italian Institute for Research & Protection of the Environment (ISPRA).

In addition, detailed species-level data for two groups (bumblebees and butterflies) were collected through the Planting for Pollinators platform, repurposed from the concluded BeeWatch project (van der Wal et al 2016). Students contributed to the design and implementation of X-Polli:Nation, resulting in the creation of a comprehensive suite of computational tools that used Artificial Intelligence to support learning activities with students through various stages of the cycle in Figure 1. These tools were (a) species identification training (cf. Figure 2), and (b) interfaces to explore species-level pollinator preferences for flowers (cf. Figure 3) and to receive pollinator-friendly planting recommendations. In parallel, the team created interactive online learning materials covering the value to society and the environment of pollinating insects, the threats they face, and 10 simple actions children can take to support pollinators.

Initially, to co-design the tools, the project team worked closely with 16 students, aged 8–11, in a state primary school in the UK (see Supplemental File 1: X-Polli:Nation Tool Student Feedback [29.3.19]). Students were members of a school club, The Hive, an enthusiastic group with interest in pollinators, conservation, and sustainability, led by their trailblazer teacher, a champion for outdoor education. This process started with a day-long workshop in March 2019, facilitated by engagement specialists, technologists, and teachers. It involved an exploration of the tools, followed by an interactive evaluation session. This involved approaches such as "voting with feet," in which students were asked to move to "yes" or "no" banners situated at opposite ends of the room, posting counters in voting boxes, and open discussions with a facilitator. The digital interface was amended and then, after completion, the tool was presented to students in June 2020 on iPads for further feedback. This second feedback session involved 8 pupils (a mixture of year 5 and 6, boys and girls), some of whom had used the tool previously and others who had not. This was facilitated by a schoolteacher who provided written feedback notes (see Supplemental File 2: X-Polli:Nation Tool Teacher Feedback [18.6.20]). We used the co-design process primarily to adapt the tools to increase their interest to and usability for children. We made the interfaces more visual and reduced and simplified the text presented. We also identified interface elements that were increasing workload; for example, dropdown lists proved difficult to navigate and were replaced in the interface with lists of buttons that could be selected (cf. Feature Filters in centre of Figure 2). Through co-design, we also calibrated difficulty

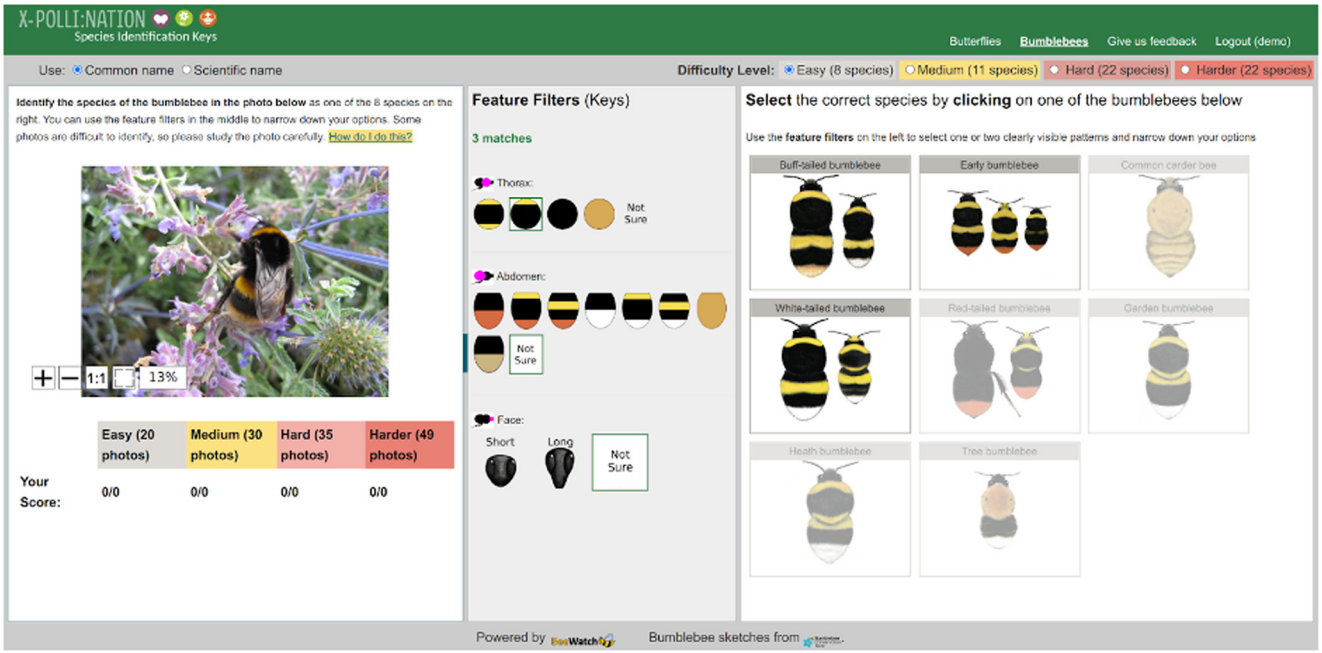

Figure 2 Screenshot showing the species identification training tool with four difficulty levels. Users can use the keys in the middle to filter out species that do not match selected features. The Hard and Harder difficulties also offer suggestions for likely species using automated image recognition.

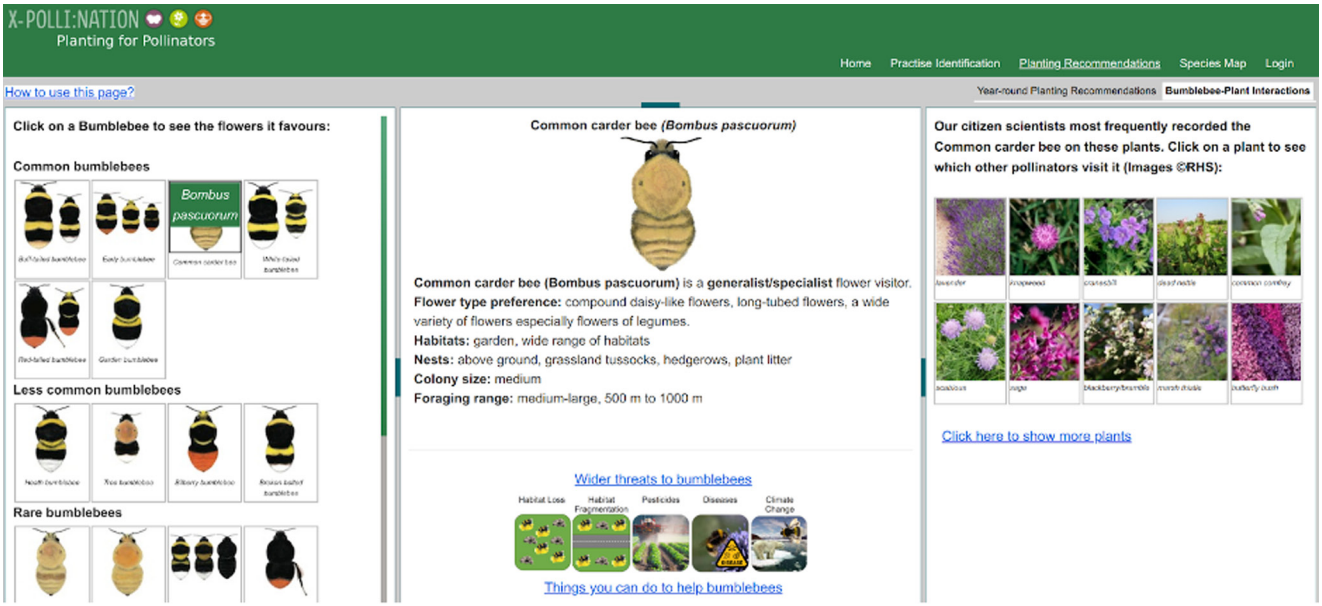

Figure 3 The Planting for Pollinators tool where users are able to click on a species of bumblebee found in the UK and find out the flowers that citizen scientists most frequently record this bumblebee visiting; in addition, users can discover threats to bumblebees.

levels on the task so that the easy level helped learners to identify the eight most common species in the UK, and the three further levels introduced species that are more difficult to distinguish and scaffolded learning through suggestions from automated image recognition.

The co-design process highlighted that students found it stimulating to help design the tools. When asked "Did you like providing feedback about scientific tools?" 14/16 (88%) students voted yes. Knowledge and confidence in species identification increased from using the tool (14/16 [88%] were more confident in identifying bumblebees after using the tool; 15/16 [94%] for butterflies), and 15/16 (94%) students stated an increased interest in nature after the activities of the session. Our impression from observing the study and interacting with the students afterwards was that they overwhelmingly enjoyed using the tool (indeed,

one student who had just completed the second round of feedback said, "this is actually fun!") and were keen to recommend it to their friends and families. Students' keenness for using the tools has since been observed across schools.

The project and its materials required some redesign for use in Italy. Apart from the obvious language translation, some plant species (flowers) and many insect species (pollinators) are different in Italy than in the UK. We tried to keep the ones common to the two countries to enhance future comparisons of the results, but had to find substitute species where this was not feasible. Another macro difference is the location where the data collection was performed, and in Italy, a choice was made to leverage the botanic gardens managed by the partner Universities as they offered grounds for planting and data collection exercises.

CONTRIBUTIONS TO THE SUSTAINABLE DEVELOPMENT GOALS

The 2030 Agenda for Sustainable Development "provides a shared blueprint for peace and prosperity for people and the planet, now and into the future," which resonates with the original aims of the X-Polli:Nation: to benefit People, Pollinators, and the Practice of CS. More than 3,000 participants (200 teachers and 2,800 students) have been involved in X-Polli:Nation across the UK and Italy with our direct facilitation, mainly focussed in two regions: Hampshire and Tuscany, respectively. We are aware of these students reaching out to 817 other members of their community to spread the word about protecting pollinators. It is likely that others have benefitted from the project, as all our resources are freely available online. The www.xpollination.org website, launched in April 2020, has been visited more than 15,000 times up to November 2022. Our @XpolliProject (#XPolli,#PolliPromise) Twitter account, launched in September 2020, has more than 300 followers and 8,000 views of posted videos up to November 2022.

RELEVANCE OF X-POLL:NATION ACROSS MULTIPLE SDGS

While the project was not conceptualised taking into account SDGs specifically, we discuss how relevant our project goals are to SDG 15, Life on Land (by learning about, recording, and taking action for pollinators); to SDG 4, Quality Education (by developing new and engaging ways of teaching sustainability); and to SDG 10, Reducing Inequality (by including children in conversations about sustainability and providing, through schools, an equitable opportunity for children of all backgrounds to experience outdoor science learning while exploring nature).

One key validation of our approach for SDG 4, Quality Education, comes from the UK's school regulating body Ofsted, which last year inspected a school during their participation in X-Polli:Nation and explicitly mentioned their pollinator work in awarding them the highest rating of "outstanding" for personal development. It was the students in this school that came up with the idea of the Pollinator Promise, an initiative that has become a core element of the communication aspect of the X-Polli:Nation CS cycle and is now referenced on the Department for Education (England) blog. When you sign up to the Pollinator Promise, you pledge to put aside single or multiple 1 m × 1 m areas in your garden, school grounds, or business to grow pollinator-friendly plants. By November 2022, 2126 Polli-promises have been made to create 5,290 m^2 of pollinator-friendly habitat. While it originated in one small school, the initiative expanded nationally and internationally. Pupils even wrote to their local MP and gave a presentation that was the subject of a subsequent Parliamentary conversation on Twitter, demonstrating the impact children can have.

The Pollinator Promise is an example of how young people can inspire and encourage others to take action in support of SDGs. Creating and maintaining wildlife-friendly habitat is key to SDG 15, Life on Land, as is the process of raising awareness, promoting action, and communicating to local communities about biodiversity loss. X-Polli:Nation also supported this goal through data collection about pollinating insects and their feeding preferences. Up until November 2022, we have collected from schools 2,386 records of pollinating insects through 238 timed surveys in the UK and 3,126 records through 327 timed surveys in Italy. Students, teachers, and scientists have all shared findings from the project in different forums, hosting a workshop at the 2020 European CS Association (ECSA) Conference, presenting a keynote at the UK's Young Nature 2021 Conference and Wildlife Trust's "Wilder" strategy, and culminating in a celebratory event with 170 primary and secondary school attendees from UK and Italy. The project's approaches and resources were shared on a global platform at a COP26 Green Zone event in Glasgow in November 2021, also receiving 1,900 views on YouTube by November 2022.

INCLUSIVITY UNDER CHANGING CIRCUMSTANCES

The COVID-19 outbreak highlighted a significant equity challenge amongst pupils who lacked access to educational resources and technologies at home, as well as access to nature and the opportunities and benefits of learning outdoors (Brooks et al. 2020; Colucci-Gray 2022). X-Polli:Nation launched just before the pandemic

hit. The key impacts of the pandemic on mainstream schooling were severe, with initial school closures, then removal of access for external organisations to schools for face-to-face delivery, and increasing constraints placed by schools struggling to catch students up with the existing curriculum. The project capitalised on the interest of schools seeking to meet the needs of children with additional learning requirements and behavioural challenges. The hands-on habitat creation work proved therapeutic for some, who chose to skip the data collection CS elements. However, some neurodiverse students really enjoyed learning to identify species using the AI-enhanced species-identification keys. Lockdown also presented some opportunities for more outdoor learning, as mainstream schools stayed open for those students who had key worker parents. One school applied X-Polli:Nation as a mechanism to build on their maths skills and to bring their whole community together. They named it Seeds of Hope and gifted bags of seeds to the community (300 bags) to help with the pandemic recovery. They won a UK government award as part of the Census 2021 Let's Count programme, and also won a Hampshire Wildlife Trust "Wilder School of the Year" award for their work on the Polli Promise, and were noted in a National Lottery Award.

One X-Polli:Nation facilitator (outdoor education specialist) worked directly with 1,113 students (ages 4–16) and 96 teachers through 15 workshops at 10 schools from 2020 through 2022. She provided written feedback on each of the sessions (see Supplemental File 3: X-Polli:Nation Adaptations within Schools—Facilitator Feedback), and we also had written correspondence with teachers (with permission to share feedback). From this information, it was clear that teachers were happy to pick and choose different elements of the cycle as a starting point (some starting with habitat surveys and creation, others with species identification), and to adapt the resources for their contexts (e.g., one teacher noted, "I varied the pace of the session by interspersing with more physical games"). Teachers also found that the resources were applicable for areas of learning not explicitly linked to by X-Polli:Nation (e.g., one said, "We linked it with our computing [video editing] and personal development [pupil voice and advocacy]").

Some teachers found it challenging to get time outdoors, and there were several technical challenges. For example, students in many schools are not allowed to have accounts on external sites, and school iPads are not on mobile networks, limiting the use of technology outdoors. We adapted our tools and Open Learn resources to not require logins, and our recording platform to allow a single school login managed by a teacher. However, because CS surveys need to follow a standardised protocol, (e.g. the survey could be conducted only when the temperature was above 12 degrees Celcius) and there is a need to input data from paper surveys into the computer when back indoors, in some situations, planned surveys either could not be conducted or were not uploaded to the recording platform.

Yet, it was encouraging how positively children's participation was noticed by the facilitator, with one commenting, "all children appeared motivated, and it was clear at the beginning that some students did not know the connection between a plant and the insect visiting it." It was students who gained the most out of these sessions, and the most activity (whether through data collection or planting) happened when teachers and facilitators actively worked together to plan and deliver the sessions.

The experience of X-Polli:Nation yielded the overarching lesson that flexibility and a variety of entry points into the cycle were key to enable participation of children, and to gain the collaboration of teachers to get involved in hands-on field-based studies and data-driven science as practised today. Understanding this way of learning is key for engaging pupils from multiple locales in CS activities, giving the chance to adapt them to their particular context but also feeding back into the project resources for further adaptation, in line with the SDG principle, "Leave No One Behind," and SDG 10, Reducing Inequality.

APPETITE FOR TAKING ACTION FOR THE SDGS IN SCHOOLS IN THE FUTURE

The premise of X-Polli:Nation was that involvement in biological recording and species identification is the window and process by which students become connected with their local nature, and interested in global challenges. The questions then were: Had the participating children and teachers heard of the SDGs? Were they interested in contributing to them?, and if so, How?

Initial discussions with school and community members at a school event where X-Polli:Nation held a stall indicated that none of the students asked had heard of the SDGs but that parents thought the topic of pollination could be relevant to multiple SDGs (Figure 4). In order to investigate knowledge of SDGs and whether there was appetite to adapt X-Polli:Nation to align with SDGs in a systematic way, an online survey for students was sent to 10 schools enrolled on the project.

Invited by the X-Polli:Nation facilitator and their teachers, 30 UK students took part in the questionnaire, all of whom were aged 8–11. Results indicated (see Supplemental File 4: X-Polli:Nation & SDG Student Evaluation) that by taking part in actionable CS projects such as X-Polli:Nation, most

Figure 4 Photo of engagement activity at the St Alban's School Nature (and Sustainability) Roadshow event, May 2022, which asked visitors which of the SDGs they thought were relevant to pollination (those stuck on painting of Bumblebee; those left below X-Polli:Nation logo were ones they didn't think were relevant).

students felt optimistic that their input could make an impact—27/30 students (90%) scored over 7 or above on a scale from 1 (no impact) to 10 (change the world) (cf. Figure 5).

Concerningly, albeit unsurprisingly perhaps, 28/30 students (93%) had not heard of the SDGs; however, when they were explained, two thirds of students said they would like to contribute towards them, and the two most popular ways were through taking action (15/30, or 50% of students) and by communicating the importance of the SDGs to others (also 15). The collection of data was less appealing; however, still a third of students (10) said they would like to record trends, and a higher number, 13 (43%), would like to learn more about the SDGs (Figure 6).

Contrary to students, teachers had indeed heard of the SDGs, and discussions with them suggested that their interest in getting more involved in teaching in line with the SDGs was very similar to the students; both favoured taking action and communicating the importance of global issues over learning and data collection.

There were, however, a number of barriers identified, including the overloaded curriculum, lack of support for teachers for outdoor learning, and working within the parameters of how schools are inspected.

Nevertheless, teachers were enthusiastic to support their students to make a difference for people and planet, and they identified practical connections across topics and disciplines:

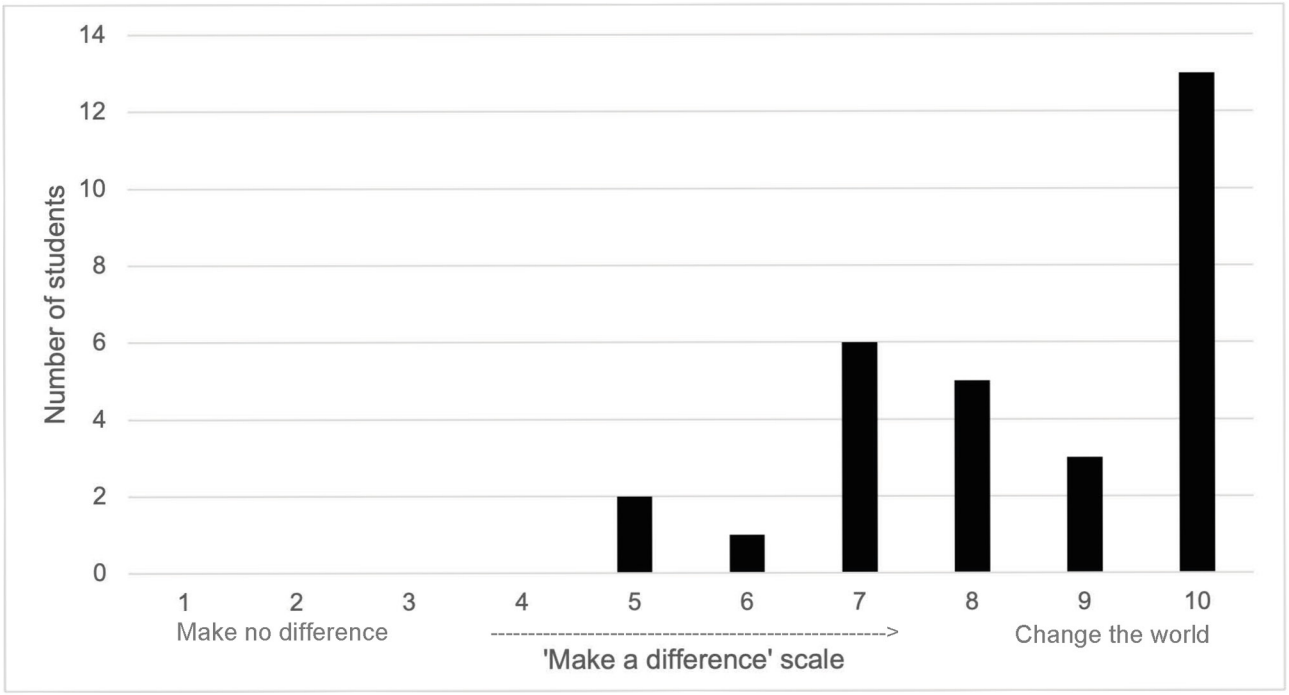

Figure 5 Student (n = 30) responses to the question "On a scale of 0 (no change) to 10 (change the world), what impact do you think that you can make by taking part in projects such as X-Polli:Nation?'

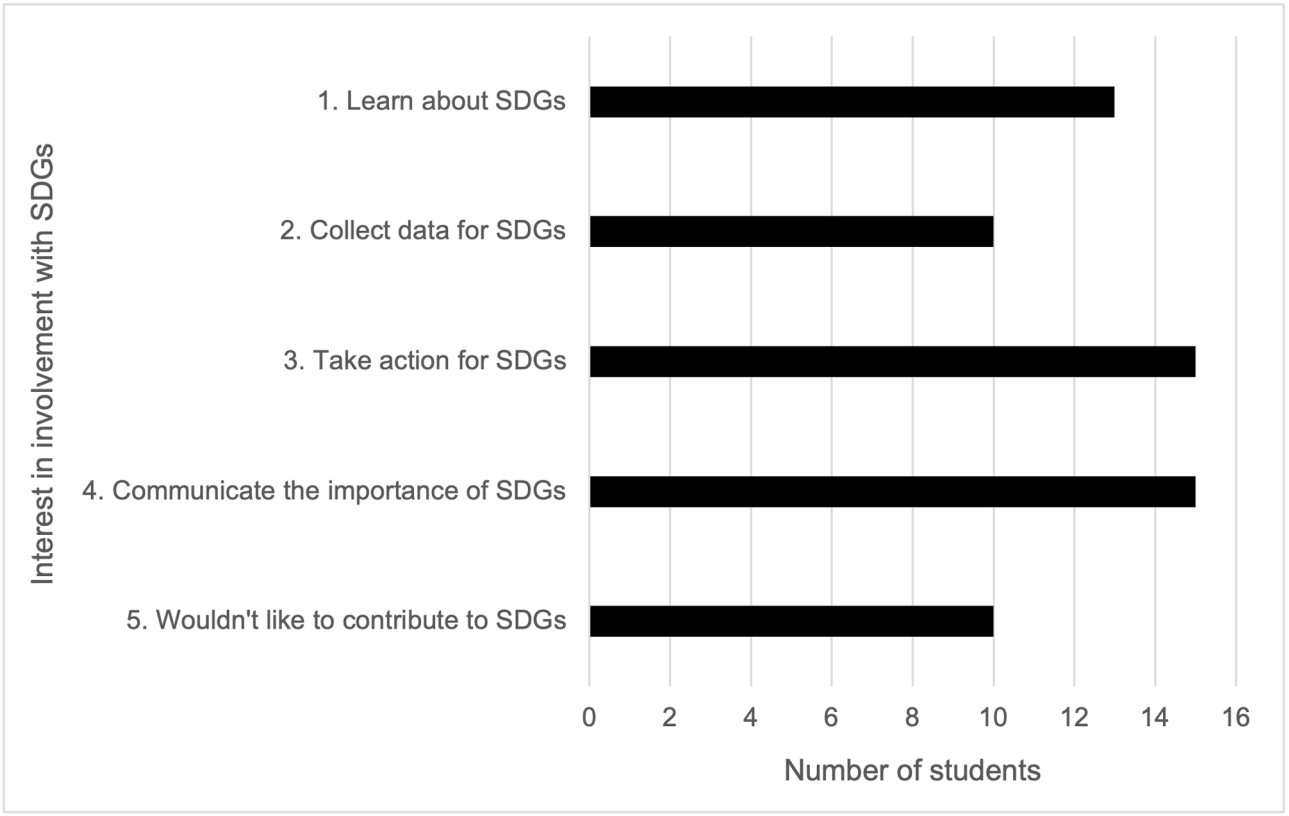

Figure 6 Student (N = 30) feedback on how they would like to contribute to global issues (such as the SDGs) to support the health of the planet and people. Students could select multiple options.

> *"Discuss global impacts on every topic I teach! Think global – act local!"*
> *"It's about listening to students, hearing what is important to them, with sincerity. Then, give them opportunities to put this into action, in ways that are of interest to them. I would like to explore ways of incorporating the arts too."*

Multiple comments came back to the fact that taking action for goals is within everyone's reach, and this is a way to make the global goals relevant on a local level.

DISCUSSION

Building upon models developed by practitioners in the field of CS-SDG, we have demonstrated how one such case study project, X-Polli:Nation, can adhere to the underlying principles of SDGs, can align with different SDGs, and can directly contribute to the sustainability agenda in different ways.

RELEVANCE TO PRINCIPLES AND ACROSS GOALS

By partnering with school children in the pursuit of pollinator citizen science, the project built on the "fortuitous alignment" approach that Cowell et al. (2022) took, inherently aligning principles of quality and equitable education with ecological awareness and action. Following Spinuzzi (2005), we showed how this project engaged with a CS approach to establish a particular kind of research practice, by inviting a diversity of contributions and enhancing different sets of capabilities. This was visible in the experience of X-Polli:Nation from when it was first set up: Participation in the project was motivated by the desire to take action towards environmental issues people fundamentally cared about, and participants took an active part in co-designing methods and objectives. This approach proved particularly powerful during the pandemic, by enabling different modalities for participation, each one attending to different needs, and each one addressing unexpected barriers (Colucci-Gray 2022). For example, when the team adapted the tools and survey method for use by schools, it enabled children from a wider range of demographics to participate in our CS project, including those with physical, learning, and behavioural challenges. It was also witnessed that most children were almost surprised to be taking part in real science, and felt valued and motivated by being told that they were contributing to the scientists' work: Learning became purposeful, and collaboration effective (Head 2003).

DIRECTLY CONTRIBUTING THROUGH DIFFERENT PROCESSES

It is important not just to consider the principles and goals themselves but the different ways in which CS can contribute as outlined by West and Pateman (2017): defining national and subnational targets and metrics, monitoring progress, and implementing action. In this regard, it is important that CS projects play a role beyond mundane data collection. Schools are an inclusive network for environmental monitoring as they exist in every society, teach a diversity of cultural and social backgrounds, and are fundamental in educating the future custodians of our planet. In X-Polli:Nation, we have seen first-hand the impacts of CS methods on participating schools and students, and how it has connected them to nature and made them keen to take actions in support of sustainability goals. This is important when considering the barriers of an overcrowded curriculum and conflicting policy priorities (Christie et al. 2019). The evidence from teachers and the Ofsted authority gathered through our project showed that CS can offer a powerful approach to develop scientific literacy while developing a broader set of civic and ecological capabilities for children.

EVOLVING CITIZEN SCIENCE PROJECTS

Research funding cycles are set up to award novel concepts, and thus funds are typically allocated to creating whole new suites of tools, approaches, and collaborators. More often than not, at the end of a funding cycle, all of those resources and the communities they supported are lost. Added to this, the siloed way in which some projects, departments, and organisations operate mean that often practitioners are unaware of similar plans or existing projects, or are in competition with them. This leads to a landscape where data is not joined up and the array of seemingly similar activities becomes confusing for participants.

X-Polli:Nation explicitly tried to address—and avoid—these pitfalls. The project evolved and continues to evolve by design, reusing and adapting existing tools and resources, and exploring different funding routes to further develop different elements of the CS cycle (cf. Figure 7).

Through these different research projects, we are building a network and resources under a single X-Polli:Nation umbrella so that (a) teachers and children can more effectively learn about, record data on, take action for, and spread the word about the importance of pollinators; (b) new teachers and schools can join and learn from existing ones and from the available online materials at www.xpollination.org; (c) existing teachers and children

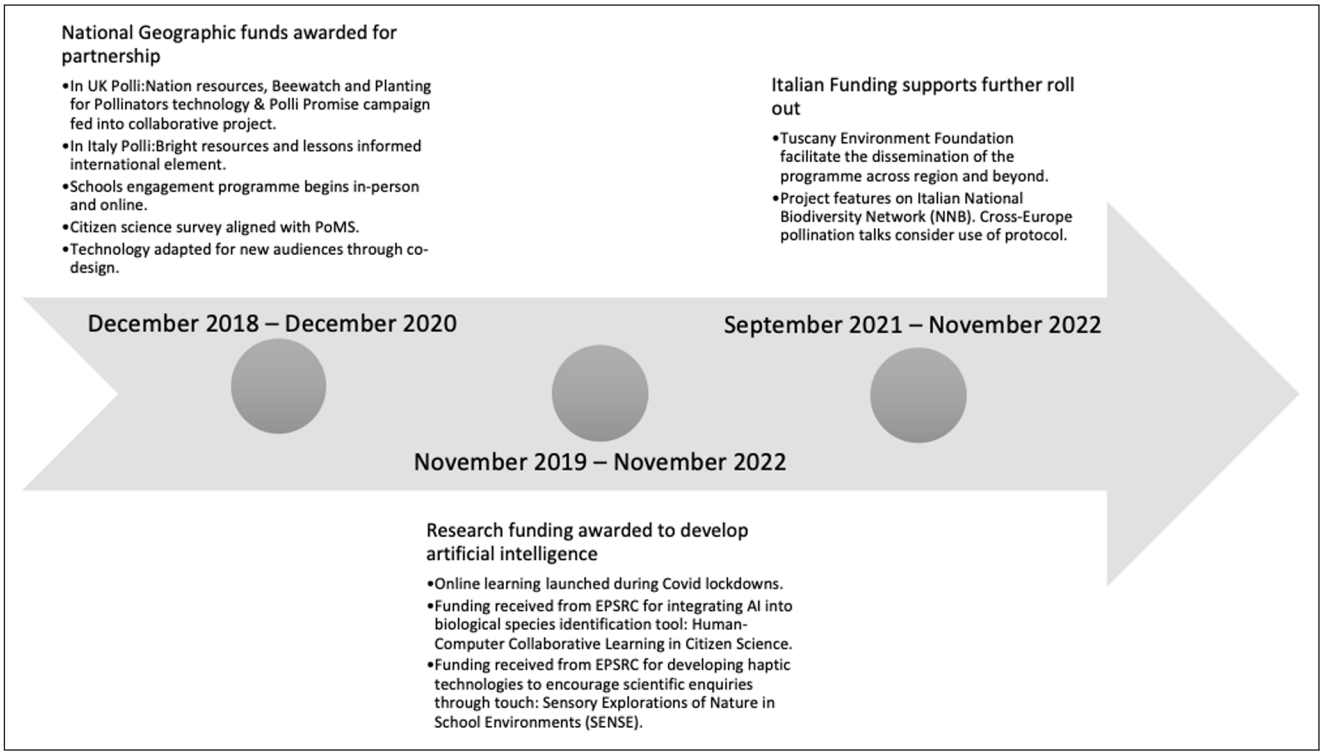

Figure 7 Direction of evolution of X-Polli:Nation through funding cycles in the UK and Italy.

can continue to discover new materials and tools as they are developed through our projects over longer timeframes; and (d) we can learn from adapting the resources for different contexts and apply these approaches to relevant frameworks (for example, the SDGs).

NEXT STEPS: HOW TO DEEPEN ALIGNMENT WITH THE SDGS

Amongst participating students, teachers, and citizen science practitioners there was a unanimous wish to contribute more deeply to the Sustainable Development Agenda. Though addressing the SDGs requires top-down commitments from governments, the SDGs can also be seen, on a personal level, as a sort of to-do list to live on a sustainable planet, a clear roadmap for a better future. X-Polli:Nation lends itself towards such an approach of taking personal responsibility for living sustainably, and X-Polli:Nation recently worked with Human, an Italian start-up (www.human-sustainability.com), to promote this idea. Human developed the recently launched MySDGs app, which invites the public to set personal goals aligned with the SDGs for a more sustainable approach to daily life, and carry out actions offered by the app that help achieve the SDGs. Participating in X-Polli:Nation is one such action offered by the MySDG app. We look forward to exploring how such personal connections with SDGs can impact CS practice, and particularly any impacts on participation for children from different communities.

If the UN systems would allow, there is untapped potential to ensure that the data journey not only ends up with professional scientists within the project team, but continues its journey through to monitoring of the indicators and targets themselves, one of which will include digital equity. Most fundamentally, further embedding these approaches could speed up the integration of the UN convention of the Rights of the Child within the education system, of which Scotland is the first nation to have fully adopted (Colucci-Gray 2022), and make sustainability core to children's experience at school. In line with Lämmerhirt et al. (2018), this would significantly strengthen science-society relationships, through closer collaboration across a network of practitioners in the CS-SDG arena, a call which we are enthusiastic to embrace as it resonates with our original premise to cross-pollinate ideas, methods, and technology for pollinator CS.

CONCLUSION

We have reported on a citizen science project that involves school children in multiple stages of the scientific process, promotes actionable CS, and supports children in adopting and promoting environmentally friendly behaviours. Our initial goal was to help children develop new scientific and citizenship competences as well as connectedness with nature, essential for environmental conservation, wellbeing, quality of life, social inclusion, and employability. Over the

course of the project, however, we grappled with important aspects of children's participation in significant issues that affect their lives. Integrating sustainability into an "already crowded curriculum," as one teacher put it, brings with it challenges; however, one of the key lessons we learnt was that it is indeed possible if flexibility and a variety of entry points into the actionable CS cycle are designed into the programme. We found it crucial to:

1. Consider the value: Given the wider context of CS practices, educational needs, and the SDG landscape, is there value for participatory projects and topics that nestle within this cross-disciplinary space?
2. Understand participants: Given the pressures both teachers and students are under to meet performance requirements, what motivates children and their teachers to work together in contributing to SDGs?
3. Adapt for different contexts: Considering the different levels of digital and scientific literacy across communities and contexts, can we design a programme that is flexible enough to meet the varied needs of different schools, teachers, and students?

Addressing the dilemma put forward by Pateman, Dyke, and West (2021) of increasing uptake of CS for sustainability when information or resources may be limited, we found that co-design was a very powerful experience for children. Students enjoyed CS because they felt they were contributing to real world data, but also because co-design empowered them and made them feel listened to. We also witnessed students gain the confidence to become passionate environmental stewards, and translate attitudinal change into civic action in support of the SDGs. Evidence from this project thus points to a significant shift in the way CS may be understood: not simply as a tool for doing science, but most importantly as a process for defining "what" science, and helping communities of young people in society to take action in the face of global environmental change. We go as far as suggesting that such a shift brings with it an important shift in education too, moving epistemic justice and the practices of children and teachers in schools to the forefront of knowledge-generation, paving the way for a sustainable future.

SUPPLEMENTARY FILES

The supplementary files for this article can be found as follows:

- **Supplemental File 1.** X-Polli:Nation Tool Student Feedback [29.3.19]). DOI: https://doi.org/10.5334/cstp.567.s1
- **Supplemental File 2.** X-Polli:Nation Tool Teacher Feedback [18.6.20]. DOI: https://doi.org/10.5334/cstp.567.s2
- **Supplemental File 3.** X-Polli:Nation Adaptations within Schools—Facilitator Feedback. DOI: https://doi.org/10.5334/cstp.567.s3
- **Supplemental File 4.** X-Polli:Nation & SDG Student Evaluation. DOI: https://doi.org/10.5334/cstp.567.s4

ETHICS AND CONSENT

The National Geographic project was reviewed on 20/3/19 by the Imperial College London Joint Research Compliance Office, which deemed that "the study does not need full ethics review" as no significant ethical issues were identified in the protocol or ethics application. The EPSRC project was reviewed and given a favourable opinion by The Open University Human Research Ethics Committee on 09/06/2020. For all the reported studies in schools, we sought separate informed consent from parents/guardians for participation and for use of images. We photographed only students with both consents, and consent from parents/guardians has been obtained for all students photographed in Figure 1.

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COMPETING INTERESTS

The authors have no competing interests to declare.

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REFERENCES

Anderson, HB, Robinson, A, Siddharthan, A, Sharma, N, Bostock, H, Salisbury, A, Roberts, S and **van der Wal, R.** 2020. Citizen science data reveals the need for keeping garden plant recommendations up-to-date to help pollinators. *Scientific reports*, 10(1): 1–8. DOI: https://doi.org/10.1038/s41598-020-77537-6

Ballerini, L and **Bergh, SI.** 2021. Using citizen science data to monitor the Sustainable Development Goals: a bottom-up analysis. *Sustainability Science*, 16(6): 1945–1962. DOI: https://doi.org/10.1007/s11625-021-01001-1

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

Brooks, SK, Webster, RK, Smith, LE, Woodland, L, Wessely, S, Greenberg, N and **Rubin, GJ.** 2020. The psychological impact of quarantine and how to reduce it: rapid review of the evidence. *The Lancet*, 395(10227): 912–920. DOI: https://doi.org/10.1016/S0140-6736(20)30460-8

Christie, E, Higgins, P, King, B, Collacott, M, Kirk, K and **Smith, H.** 2019. From rhetoric to reality: Examining the policy vision and the professional process of enacting Learning for Sustainability in Scottish schools. *Scottish Educational Review*, 51(1): 44–56. DOI: https://doi.org/10.1163/27730840-05101006

Ciasullo, MV, Manna, R and **Palumbo, R.** 2019. Developing a taxonomy of citizen science projects in primary school: Toward sustainable educational quality co-production. *TQM Journal*, 31(6): 948–967. DOI: https://doi.org/10.1108/TQM-03-2019-0083

Colucci-Gray, L. 2022. Reviewing the impact of COVID-19 on children's rights to, in and through education. *The International Journal of Human Rights*, 1–17. DOI: https://doi.org/10.1080/13642987.2022.2057961

Cowell, CR, Bullough, LA, Dhanda, S, Harrison Neves, V, Ikin, E, Moore, J, Purdon, R, Williams, C, Willison, J and **Willoughby, SJ.** 2022. Fortuitous alignment: The Royal Botanic Gardens, Kew and the Sustainable Development Goals. *Sustainability*, 14(4). 2366. DOI: https://doi.org/10.3390/su14042366

Dicks, LV, Breeze, TD, Ngo, HT, Senapathi, D, An, J, Aizen, MA, Basu, P, Buchori, D, Galetto, L, Garibaldi, LA, Gemmill-Herren, B, Howlett, BG, Imperatriz-Fonseca, VL, Johnson, SD, Kovács-Hostyánszki, A, Kwon, YJ, Lattorff, HMG, Lungharwo, T, Seymour, CL, Vanbergen, AJ and **Potts, SG.** 2021. A global-scale expert assessment of drivers and risks associated with pollinator decline. *Nature Ecology and Evolution*, 5(10): 1453–1461. DOI: https://doi.org/10.1038/s41559-021-01534-9

Dillon, J, Stevenson, RB and **Wals, AEJ.** 2016. Introduction to the special section Moving from Citizen to Civic Science to Address Wicked Conservation Problems. *Conservation Biology*, 30(3): 450–455. DOI: https://doi.org/10.1111/cobi.12689

Dupret, K and **Chimirri, NA.** 2018. Teaching ethical-participatory social design. *Dansk Universitetspædagogisk Tidsskrift*, 24: 20–36. DOI: https://doi.org/10.7146/dut.v13i24.96709

Fraisl, D, Campbell, J, See, L, Wehn, U, Wardlaw, J, Gold, M, Moorthy, I, Arias, R, Piera, J, Oliver, JL, Masó, J, Penker, M and **Fritz, S.** 2020. Mapping citizen science contributions to the UN sustainable development goals. *Sustainability Science*, 15(6): 1735–1751. DOI: https://doi.org/10.1007/s11625-020-00833-7

Gill, RJ, Baldock, KCR, Brown, MJF, Cresswell, JE, Dicks, LV, Fountain, MT, Garratt, MPD, Gough, LA, Heard, MS, Holland, JM, Ollerton, J, Stone, GN, Tang, CQ, Vanbergen, AJ, Vogler, AP, Woodward, G, Arce, AN, Boatman, ND, Brand-Hardy, R, Breeze, TD, Green, M, Hartfield, CM, O'Connor, RS, Osborne, JL, Phillips, J, Sutton, PB and **Potts, SG.** 2016. Protecting an Ecosystem Service: Approaches to Understanding and Mitigating Threats to Wild Insect Pollinators. In: *Advances in Ecological Research*, 135–206. Academic Press Inc. DOI: https://doi.org/10.1016/bs.aecr.2015.10.007

Gupta, N, Slawson, DD and **Moffat, AJ.** 2022. Using citizen science for early detection of tree pests and diseases: perceptions of professional and public participants. *Biological Invasions*, 24(1): 123–138. DOI: https://doi.org/10.1007/s10530-021-02631-3

Hargreaves, A. 1992. Cultures of teaching: a focus for change. In: Hargreaves, A and Fullan, M (eds.), *Understanding teacher development*. London: Cassell.

Haywood, BK and **Besley, JC.** 2014. Education, outreach, and inclusive engagement: Towards integrated indicators of successful program outcomes in participatory science. *Public Understanding of Science*, 23(1): 92–106. DOI: https://doi.org/10.1177/0963662513494560

Head, G. 2003. Effective collaboration: Deep collaboration as an essential element of the learning process. *Journal of Educational Enquiry*, 4(2): 47–62.

Heigl, F, Kieslinger, B, Paul, KT, Uhlik, J and **Dörler, D.** 2019. Toward an international definition of citizen science. *Proceedings of the National Academy of Sciences of the United States of America*. 116(17): 8089–8092. DOI: https://doi.org/10.1073/pnas.1903393116

Hofstein, A, Eilks, I and **Bybee, R.** 2011. Societal Issues and Their Importance for Contemporary Science Education- a Pedagogical Justification and the State-of-the-art in Israel, Germany and the USA. *International Journal of Science and Mathematics Education*, 9(6): 1459–1483. DOI: https://doi.org/10.1007/s10763-010-9273-9

Irwin, A. 1995. *Citizen Science: a study of people, expertise and sustainable development*. New York: Routledge.

Kelemen-Finan, J, Scheuch, M and **Winter, S.** 2018. Contributions from citizen science to science education: an examination of a biodiversity citizen science project with schools in Central Europe. *International Journal of Science Education*, 40(17): 2078–2098. DOI: https://doi.org/10.1080/09500693.2018.1520405

Klein, A-M, Vaissière, BE, Cane, JH, Steffan-Dewenter, I, Cunningham, SA, Kremen, C and **Tscharntke, T.** 2007. Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences*, 274(1608): 303–313. DOI: https://doi.org/10.1098/rspb.2006.3721

Kullenberg, C and **Kasperowski, D.** 2016. What is citizen science? – A scientometric meta-analysis. *PLoS ONE*, 11(1): e0147152. DOI: https://doi.org/10.1371/journal.pone.0147152

Lämmerhirt, D, Gray, J, Venturini, T and **Meunier, A.** 2018. Advancing sustainability together? *Citizen-generated data and the Sustainable Development Goals*. DOI: https://doi.org/10.2139/ssrn.3320467

Merzagora, M and **Jenkins, T.** 2013. Listening and empowering: children and science communication. *Journal of Science Communication*, 12(3): 1–3. DOI: https://doi.org/10.22323/2.12030301

Meynhardt, T, Chandler, JD and **Strathoff, P.** 2016. Systemic principles of value co-creation: synergetics of value and service ecosystems. *Journal of Business Research*, 69: 2981–2989. DOI: https://doi.org/10.1016/j.jbusres.2016.02.031

Ollerton, J. 2021. *Pollinator and Pollination: Nature and Society*. Exeter, UK: Pelagic Publishing.

Patel, V, Pauli, N, Biggs, E, Barbour, L and **Boruff, B.** 2021. Why bees are critical for achieving sustainable development. *Ambio*, 50(1): 49–59. DOI: https://doi.org/10.1007/s13280-020-01333-9

Pateman, R, Dyke, A and **West, S.** 2021. The diversity of participants in environmental citizen science. *Citizen Science: Theory and Practice*, 6(1): 1–16. DOI: https://doi.org/10.5334/cstp.369

Ruiz-Mallén, I, Riboli-Sasco, L, Ribrault, C, Heras, M, Laguna, D, and **Perié, L.** 2016. Citizen Science: Toward Transformative Learning. *Science Communication*, 38(4): 523–534. DOI: https://doi.org/10.1177/1075547016642241

Severcan, YC. 2015. Planning for the Unexpected: Barriers to Young People's Participation in Planning in Disadvantaged Communities. *International Planning Studies*, 20(3): 251–269. DOI: https://doi.org/10.1080/13563475.2014.985195

Siddharthan, A, Lambin, C, Robinson, A-M, Sharma, N, Comont, R, O'mahony, E, Mellish, C and **van der Wal, R.** 2016. Crowdsourcing without a crowd: Reliable online species identification using Bayesian models to minimize crowd size. *ACM Transactions on Intelligent Systems and Technology*, 7(4): 1–20. DOI: https://doi.org/10.1145/2776896

Spinuzzi, C. 2005. The Methodology of Participatory Design. *Technical Communication*, 52(2): 163–174.

Trautmann, NM, Shirk, JL, Fee, J and **Krasny, ME.** 2012. Who Poses the Question? Using Citizen Science to Help K–12 Teachers Meet the Mandate for Inquiry. In: Dickinson, JL and Bonney, R (eds.), *Citizen Science: Public Participation in Environmental Research*, 179–190. NY: Cornell University Press. DOI: https://doi.org/10.7591/cornell/9780801449116.003.0013

United Nations General Assembly. 2015. *Transforming our world: the 2030 Agenda for Sustainable Development*; Publisher, UN General Assembly; Publication Date, 21 October 2015.

van der Wal, R, Sharma, N, Mellish, C, Robinson, A and **Siddharthan, A.** 2016. The role of automated feedback in training and retaining biological recorders for citizen science. *Conservation Biology*, 30(3): 550–561. DOI: https://doi.org/10.1111/cobi.12705

van Haeften, S, Milic, A, Addison-Smith, B, Butcher, C and **Davies, JM.** 2021. Grass Gazers: Using citizen science as a tool to facilitate practical and online science learning for secondary school students during the COVID-19 lockdown. *Ecology and Evolution*, 11(8): 3488–3500. DOI: https://doi.org/10.1002/ece3.6948

Vohland, K, Land-Zandstra, A, Ceccaroni, L, Lemmens, R, Perelló, J, Ponti, M, Samson, R and **Wagenknecht, K.** 2021. The Science of Citizen Science. Cham: Springer. DOI: https://doi.org/10.1007/978-3-030-58278-4

West, S and **Pateman, R.** 2017. *How could citizen science support the Sustainable Development Goals?* Stockholm: SEI. Available from: https://www.sei.org/mediamanager/documents/Publications/SEI-2017-PB-citizen-science-sdgs.pdf.

Wibowo, AT, Siddharthan, A, Anderson, H, Robinson, A, Sharma, N, Bostock, H, Salisbury, A, Comont, R and **van der Wal, R.** 2017. Bumblebee friendly planting recommendations with citizen science data. In: *Proceedings of the International Workshop on Recommender Systems for Citizens*, 1–6. New York, NY, USA: ACM; 31 August 2017. DOI: https://doi.org/10.1145/3127325.3128330

Woodcock, BA, Garratt, MPD, Powney, GD, Shaw, RF, Osborne, JL, Soroka, J, Lindström, SAM, Stanley, D, Ouvrard, P, Edwards, ME, Jauker, F, McCracken, ME, Zou, Y, Potts, SG, Rundlöf, M, Noriega, JA, Greenop, A, Smith, HG, Bommarco, R, van der Werf, W, Stout, JC, Steffan-Dewenter, I, Morandin, L, Bullock, JM and **Pywell, RF.** 2019. Meta-analysis reveals that pollinator functional diversity and abundance enhance crop pollination and yield. *Nature Communications*, 10(1): 1481. DOI: https://doi.org/10.1038/s41467-019-09393-6

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