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On2Science—Multiple affordances for learning through participation in online citizen science

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Abstract

This research investigated the integration of learning in science and digital technologies, with online citizen science (OCS) projects acting as the fulcrum for curriculum design. Across 3 years, teacher-researchers designed and implemented 16 innovative cross-curricular programmes. Our research focused on three areas: (1) mapping progressions in students' science capabilities; (2) identifying affordances of OCS engagement for developing students' digital technologies progress outcomes; and (3) investigating the impacts of teacher practices in relation to human–computer interactions. The project outcomes have potential to contribute significantly to both science and technology education research and teaching.

1. Introduction

This research project brought together a team of education and information science researchers, teacher professional learning providers, and teacher practitioners as teacher-researchers. Our aim was to explore the affordances of embedding online citizen science (OCS) projects into classroom teaching and learning programmes. The data collection took place from January 2020 to June 2023, with some data collected during the COVID-19 lockdowns and distance (home) learning. The project paused from January to June 2022 because of ongoing impacts of COVID across the education sector. In all, teacher-researchers implemented 16 teaching interventions. The research focused on students' learning in science and in digital technologies, together with human–computer interactions to support learning. It extends a previous TLRI-funded project that demonstrated that OCS projects could be meaningfully embedded in primary science programmes (Luczak-Roesch et al., 2019).

In citizen science (CS) projects, volunteer participants (called "citizen scientists") undertake scientific work in collaboration with or under the direction of professional scientists (Eitzel et al., 2017). This may include contributing to data collection, data processing, data analysis and interpretation, and/or dissemination of results (Crowston et al., 2018). In OCS projects, participants' contributions are mediated through the internet—giving anyone with a digital device and internet connection access to authentic science research projects. Large datasets can be curated and analysed, and communication is enabled between geographically disparate contributors.

With the growth in CS and OCS projects, interest has turned internationally to the impacts of engaging with these projects within school teaching and learning programmes, and a recent systematic review of learning through OCS projects highlighted the need for studies investigating the impacts of engaging with OCS projects in formal education (Aristeidou & Herodotou, 2020). Our work contributes to this nascent field of study.

Our project was established to contribute to emergent needs in the education landscape in Aotearoa New Zealand. First, we sought to build on work by the Ministry of Education (2019) to identify progress indicators for the science capabilities at curriculum Levels 2 and 4, using the National Monitoring Study of Student Achievement (NMSSA). Second, the project was timed to give insights into how the new digital technologies progress outcomes might be implemented within cross-curricular teaching and learning. Third, the OCS projects provided opportunities to investigate the impact of teacher practices when students work with digital devices.

Our research questions were:

1. What are indicators of progress in students' development of science capabilities for citizenship?
2. How does participating in online citizen science (OCS) projects contribute to the digital technology (DT) progress outcomes newly introduced into *The New Zealand Curriculum* (*NZC*) (Ministry of Education [MoE], 2017)?
3. Regarding human–computer interactions (HCI), what influences teachers' practices when students use devices, and what is the impact of these practices?

2. Rationale for the project

2.1 Science education in New Zealand

New Zealand, like many educational jurisdictions, is experiencing a decline in student engagement in school science as students move through the education system (e.g., Caygil, Hanlar et al., 2016; Caygil, Singh et al., 2016). NMSSA also reports that students at Year 8 are not achieving the expected learning outcomes in science, particularly in relation to the Nature of Science strand (EARU & NZCER, 2019).

To help teachers to bring the different parts of *NZC* together in relation to science, MoE identified five science capabilities: gather and interpret data; use evidence; critique evidence; interpret representations; and engage with science. These were published online in 2014, alongside a set of resources and very broad descriptions of how tasks might differ at the different curriculum levels[1] (https://scienceonline.tki.org.nz/Science-capabilities-for-citizenship/Five-science-capabilities). However, teacher professional learning opportunities in relation to the science capabilities are variable (Wylie & MacDonald, 2020) as is the implementation of primary science in general (Education Review Office, 2021a, 2021b).

Our research sought to further investigate progression in science capability development. Two key documents informed our work. First, Bull (2015) suggested using overall teacher judgements of how closely students resemble an "ideal" profile, with assessment tasks focusing on identifying next learning steps. Three "ideal" profiles were provided with the intention of giving teachers "ideas about how to further extend their students" while "maintaining the holistic nature of the capabilities" (p. 11). Second, NMSSA 2017 focused on science and was substantially based on the science capabilities. The data, from over 2,000 students in Year 4 and Year 8, were analysed for evidence of progress in the five science capabilities. The resultant "rainbow diagram" (MoE, 2019, pp. 6–7) provided some draft indicators of progress for Level 2, above Level 2, Level 4, and above Level 4. However, gaps in the NMSSA data meant that some of the levels were not populated for each of the science capabilities. Further, it was not clear from the NMSSA data how much teaching had occurred in relation to each science capability. Our research contributes further empirical evidence of indicators of progress in science capability development, and how teachers can support ongoing learning.

2.2 Digital technologies in the technology curriculum

A second initiative in the education landscape salient to our research was the 2017 release of the DT curriculum, which includes progress outcomes (POs) for "computational thinking for digital technologies" (CT) and "designing and developing digital outcomes" (DDDO). The expectation is that "[a]s for all parts of the curriculum, teachers will design learning programmes with *rich and authentic local contexts* that provide quality learning experiences for students" (MoE, n.d.a, italics added). Full implementation was to occur by 2020. DT progress outcomes were therefore relatively new to teachers at the start of this research, presenting a timely opportunity to investigate how experienced teachers might integrate DT learning into wider units of learning. We investigated ways in which OCS projects might inspire integrated curriculum design and support students' learning in both science and DT.

2.3 Human–computer interactions

HCI is a field of study focusing on the ways in which humans interact with computers (including hardware and software), and the implications for technological design. Our third research thread therefore focused on HCI when students engage with OCS projects in their school programmes. This thread picked up on findings from the 2018 TLRI pilot research, where it was argued that insights into how the OCS projects are used in educational settings are important for other teachers and school leaders, as well as for professional scientists and OCS platform designers (Pierson et al., 2020). This thread also recognised the immense investment that MoE and schools contribute to digital technologies and the need to maximise this investment through effective pedagogical practice.

1 *The New Zealand Curriculum* (MoE, 2007) presents achievement objectives for eight levels spread across the 13 years of school.

3. Research design

This research was embedded within a Communities of Practice (CoP) model (Townley, 2020) and our research design was guided by an interpretivist research paradigm (Norwich, 2020). Across the 3 years of the project, teacher-researchers worked together with the wider project team to plan classroom units of work that embedded one or more OCS projects. Each of these units was designed to focus specifically on one or two science capabilities, being cognisant that "In any learning activity the teacher must choose what to foreground in the moment" (Hipkins & Bull, 2015, p. 129). Some of the units were specifically designed to integrate DT progress outcomes. Each unit was implemented in the teacher's classroom, making up individual case studies.

Nine teacher-researchers contributed across the project, although natural attrition from the profession meant that only three contributed to the project in all three project years. The year levels that the teacher-researchers were teaching and the schools they were teaching at are detailed in Table 1. Four of the teacher-researchers—Carol, Matt, Melissa, and Dianne—had contributed to the 2018 pilot project and joined this project as "teacher champions", particularly in relation to using OCS projects and supporting students to develop science capabilities for citizenship. The other teacher-researchers were known to the research team as being interested in developing innovative science education practice. They were included to enable us to investigate the potential of OCS projects to enhance student learning outcomes across a wider range of curriculum levels. While two of the teacher-researchers (Richie and Harriet) were still relatively new to the profession (2–3 years of teaching experience when joining the project), the others were all very experienced. Six of the teacher-researchers had previously completed the Science Teaching Leadership Programme (STLP) funded by the Ministry of Business, Innovation and Employment (MBIE) (Carol, Matt, Rose, Melissa, Dianne, and Alana), during which they participated in intensive professional learning and development around the science capabilities. Both Dianne and Carol have previously received the Prime Minister's Science Teaching Award. In other words, there was extensive science education experience across the team. This was considered to be useful given the novelty of the OCS and DT contexts, and our intention through the research project to investigate potential for impact. The project, developed over 3 years, enabled a shift in emphasis across the three research threads over the 3 years, and supported a strongly enabling trajectory in which participating teachers could develop as both practitioners and researchers.

The nine schools represent a range of deciles and rich multicultural diversity. For example, in 2020, Hampton Hill School was decile 6 with 27% Māori and 16% Pacific students, Boulcott School was decile 8 with 15% Māori students and 5% Pacific students, Koraunui School was decile 3 with 43% Māori and 27% Pacific students, Avalon Intermediate was decile 2 with 46% Māori and 33% Pacific students, Thorndon Normal School was decile 10, with 8% Māori and 3% Pacific students, and Newlands College was decile 9 with 14% Māori and 8% Pacific students.

TABLE 1. **Teacher-researchers**

	2020	2021	2022/2023
Carol Brieseman	Years 4–6 Hampton Hill School	Years 5–6 Hampton Hill School	
Matt Boucher	Years 5–8 Thorndon School	Years 7–8 Raroa Intermediate	Years 7–8 Raroa Intermediate
Rose Campbell	Years 7–8 Avalon Intermediate School		
Melissa Coton	Years 5–6 Boulcott School	Years 5–6 Boulcott School	Years 5–6 Boulcott School
Dianne Christensen	Years 4–6 Koraunui School	Years 4–6 Koraunui School	Years 4–6 Whareama School
Alana Cockburn		Year 10 Wellington East Girls' College	
Ally Clark		Years 7–8 South Wellington Intermediate	
Richie Miller	Year 9 Newlands College	Year 9 Newlands College	
Harriet Quin			Years 7–8 South Raroa Intermediate

Research data included a combination of teacher-researchers' planning documents; teachers' verbal reports at project team meetings; teachers' pre- and post-intervention questionnaires; classroom observation notes by researchers and research assistants; copies of student work; focus group discussions with students; and student questionnaires. Logistical constraints and changes in our approach over time meant that not all these data sources were collected for each case study.

Both inductive and deductive analyses were used as appropriate. For example, in relation to the indicators of progression in students' science capability development, MoE's (2019) "rainbow diagram" of draft indicators of science capability progress was used to guide deductive analysis. This involved organising the data corpus and looking for examples of each of the science capabilities, including those described in the rainbow diagram, and other examples of the capabilities that were not explicit in the rainbow diagram. Inductive analysis—where codes are developed during analysis (Bingham, 2023)—resulted in the findings related to research questions 2 and 3. Across the project, the university-based members of the research team collaborated on completing a first round of analysis, which we then shared with the teacher-researchers for discussion. This resulted in clarification of themes and insights, and at times the emergence of new themes and/or the reduction of smaller themes into larger themes and contributed to the trustworthiness of the research. Teacher-researchers were actively involved in the dissemination of findings through conference presentations and journal publications.

4. Key findings

4.1 Progression in students' development of science capabilities for citizenship

Our first research question was initially framed as: *What indicators of progression in students' development of science capabilities for citizenship (SC) can be identified by tracking student cohorts engaging in online citizen science (OCS) over successive years?* However, the challenges with tracking students' progress across years, with student and teacher mobility and multiple teacher and school pathways, meant that we reframed this question to ask: *What are indicators of progress in students' development of science capabilities for citizenship (SC)?*

Teacher-researchers had autonomy over the science capabilities that they wanted to focus on in their intervention units. Their decisions reflected a range of considerations, including the broad science context of learning, their choice of OCS project and how it related to and informed the unit plan, students' prior learning, planning for science capability learning across multiple science units, and teachers' understanding of and confidence working with the different science capabilities.

Our major finding is that students can demonstrate science capability (SC) development at a much higher level than the NMSSA progress indicators suggest for their age and curriculum level when the SC is an explicit focus of carefully orchestrated teaching and learning. For example, many of the Years 4–6 students (Levels 2–3) in our research met at least some of the NMSSA progress indicators for Level 4 or above by the end of the unit (i.e., student progression in SC development is a function of the nature and quality of teaching they experience). Those who achieved beyond their curriculum level, as proposed by the NMSSA progress indicators, were in classes where teachers provided a sequence of learning experiences intentionally designed to support the development of the focus SC. The science capabilities—and scientific thinking—were evident where students had been supported to develop these. Below, representative case studies are used to provide evidence of this finding.

4.1.1 Gather and interpret data

The OCS projects that best supported the students' learning to gather and interpret data were projects where students collected and uploaded their own data into the project's database (e.g., *Marine Metre Squared, The Great Kiwi Earthworm Survey, Wild Sourdough*). OCS projects that provide sufficient visible links between data and their relevance also offer potential for supporting students to develop the gathering and interpreting data capability. For example, *Fossil Atmospheres* uses leaf stomata counts as paleoclimate proxies. With projects like this, teachers need to ensure that students have opportunities to compare data from different sources (e.g., magnified images of present day cf. fossilised gingko leaves) and consider the implications.

Di's Years 4–6 students (Levels 2–3), contributing to *Marine Metre Squared*, went on several trips to two local rocky shores; one within a marine reserve and the other beyond it. Multiple visits enabled the students to familiarise themselves with the sites, building on prior experiences and deepening the students' connection with the sites (Christenson et al., 2021). Deliberate teaching of relevant concepts and skills prior to data collection ensured that students understood why quadrats were used for sampling areas and were familiar with the project ID guides for organism identification. Local experts provided additional support on the beach trips. NMSSA progress indicators for gathering and interpreting data are presented in Table 2, alongside findings from our study.

TABLE 2. **Indicators of progress for gathering and interpreting data**

	NMSSA progress indicators (Aspects demonstrated by case study students are in **bold**)	**Summary of observations about Di's Years 4–6 student capability** (Aspects not referenced in the NMSSA progress indicators are underlined)
Level 2	- **Make observations about** events and **objects using their senses** - **Use simple descriptive vocabulary** - **Shape simple explanations, drawing on their observations** - **Ask simple questions about familiar contexts**	Year 4 students can: - make observations using their senses and use systematic measurement - use classification guides and descriptive vocabulary to describe organism features and justify classification decisions - start to notice differences in patterns between data gathered at the two different rocky shore sites, and at different positions along the rocky shore at each site—leading to new questions that could be further investigated - show persistence and perseverance in gathering and interpreting data - show a commitment to accuracy in data collection and data interpretation - understand that scientific data can be collected through a variety of approaches - explain the importance of data collection protocols, including replications and random sampling
Above Level 2	- **Make observations about** events, **objects**, and simple texts - **Shape simple but clear descriptions using some precise vocabulary** - **Shape simple science explanations, drawing on direct observations and evidence from sources such as photographs** - Ask simple science questions that can be investigated - **Notice and describe simple patterns involving differences** - Use basic science investigatory practices, including **systematic measurement**	
Level 4	- **Make observations about** events, **objects**, and formal science texts - **Shape descriptions that cover some features in detail and include some scientific vocabulary** - Shape science explanations, drawing on experience and their emerging science understandings - **Identify questions that can be investigated** from a set of alternatives - Identify and describe more complex patterns involving similarities and differences - Recognise why fair testing is important in gathering data	Year 4 students can: - understand that scientific data can be collected through a variety of approaches

	NMSSA progress indicators (Aspects demonstrated by case study students are in **bold**)	Summary of observations about Di's Years 4–6 student capability (Aspects not referenced in the NMSSA progress indicators are <u>underlined</u>)
Above Level 4	- **Make detailed observations about** events, **objects**, and formal science texts - **Shape descriptions that cover multiple salient features in detail and include scientific vocabulary** - Shape science explanations, drawing on basic science concepts - Ask questions that can be investigated in relation to more complex science ideas - Describe patterns, trends, and relationships from more than one data source - **Recognise methods for obtaining reliable and valid data**	

Alana's Year 10 students, who were contributing to *The Great Kiwi Earthworm Survey*, demonstrated many of the same data gathering and interpretation capabilities. We noted that these Year 10 students could follow the data collection protocols more quickly, with less scaffolding, compared to the younger Years 4–6 students. In both cases, students analysed the data they had collected.

4.1.2 Use evidence

Three case studies focused on the SC use evidence. Matt and Harriet designed a Years 7–8 unit that used the Sun as the context for learning. Richie similarly chose an astronomical context, with Year 9 students needing to use evidence collated through the unit to respond to the unit's inquiry focus: Can humans live on Mars? Richie taught the unit twice, with some differences, in 2020 and 2021. Across the three cases, the assessment tasks required students to identify and articulate relevant evidence obtained through purposefully selected learning activities through the unit. For example, Matt and Harriet's students were required to identify and respond to a common misconception about the Sun. They could present their responses as a video of a live news bulletin, a "myth busters" video, or a newspaper report. In Richie's first iteration of his unit, students wrote a scaffolded response to the inquiry question. In the second iteration, they created videos in a TV game show format using sock puppets. In each case, analysis of the students' work highlighted the importance of clear assessment criteria focusing on the use of evidence and the value of iterative timely feedback to students linking to these criteria. Richie's case also demonstrated the value of a journal in which students regularly identified evidence that would inform their response to the inquiry question (Buntting et al., 2022).

Highlighting the intersecting nature of the science capabilities, in Di's *Marine Metre Squared* case study, described above, students demonstrated an ability to use evidence (including disconfirming evidence) to justify their classification of marine organisms. This was particularly evident when organisms within a classification group looked very similar and multiple physical features needed to be considered. In Carol's Years 4–6 class, who contributed to *Skink Spotter,* identifying the presence of skinks in motion-action generated photos, students were able to articulate that "no skinks is also evidence", recognising that the photos without skinks were important sources of data.

NMSSA progress indicators for using evidence are presented in Table 3, alongside our findings. We note that young children can be expected to use evidence to support their claims, and that they can be expected to identify and use disconfirming evidence. Using multiple sources of evidence is also an indicator of capability progress. Of course, using evidence is also closely interwoven with critiquing evidence.

TABLE 3. **Indicators of progress for using evidence**

	NMSSA progress indicators (Aspects demonstrated by case study students are in **bold**)	**Summary of observations about student capability** (Aspects not referenced in the NMSSA progress indicators at a particular level are <u>underlined</u>)
Level 2	- Make claims without supporting evidence	Year 4 students can: - <u>use evidence to justify their claims</u> - <u>identify and use disconfirming evidence</u>
Above Level 2	- **Make claims and justify them with evidence** - Use reasoning to get from knowns to unknowns in simple, familiar contexts	
Level 4	- Systematically compare data to justify claims - Use logical reasoning to identify simple, plausible explanations	
Above Level 4	- **Identify disconfirming evidence** - Use stronger reasoning and critical thinking to eliminate superficially plausible options	Years 7–8 students can: - demonstrate an ability to eliminate superficially plausible options (the requirement to address a common misconception about the Sun was especially useful for surfacing this) Year 9 students can: - weigh up <u>multiple sources of evidence</u> - consider the <u>reliability of secondary sources</u> (e.g., identifying NASA as a reliable source of information for supporting a claim) (see the SC critique evidence, below) and seeking empirical evidence supporting claims in secondary sources

4.1.3 Critique evidence

This SC was a specific focus for only one case study, Melissa's Years 5–6 Sourdough unit—which unfortunately was significantly impacted by the COVID-19 lockdowns. However, overlaps in the progress indicators with the SC gather and interpret data and use evidence provide us with additional insights. We also reviewed an earlier intervention by Melissa, implemented during the 2018 TLRI-funded pilot project (Anderson et al., 2020). This case demonstrated that most of Melissa's Years 5–6 students were able to identify problems in the data associated with the OCS project—*Globe at Night*—and to varying degrees they were able to check data for differences in patterns (Level 4, see Table 4 below), and identify possible sources of error (above Level 4). In both interventions, Melissa designed activities to specifically support students to critique data, and made their successful practice explicit for the class.

Across the case studies, it became clear that critiquing evidence is closely interwoven with both using evidence (selecting evidence to use involves critiquing its reliability) and gathering and interpreting data. We suggest that learning and discussing reliable ways to collect and interpret data helps to build conceptual knowledge and grows students' ability to critique their own and others' data. What was less apparent from our case studies was how transferable the ability to critique evidence is. This is important, given the need for citizens to be able to evaluate claims and identify misinformation, disinformation, and malinformation.

TABLE 4. **Indicators of progress for critiquing evidence**

	NMSSA progress indicators (Aspects demonstrated by case study students are in **bold**)	**Summary of observations about Melissa's Years 5–6 student capability** (Aspects not referenced in the NMSSA progress indicators are underlined)
Level 2		- The absence of an indicator for Level 2 from the NMSSA data does not mean that young children cannot critique evidence. However, no case studies in our research specifically focused on this science capability with young children
Above Level 2	- Identify a problem in the data	Years 5–6 students can: - explain <u>why scientific data need to be accurate</u> (i.e., reliable) - explain why subjective data (e.g., using an aroma wheel) is less reliable than objective data (e.g., measuring the height of the sourdough) - explain why data gathering protocols are important
Level 4	- **Check data** and explanations **for differences and patterns**	
Above Level 4	- Check data and explanations to identify possible sources of error - Identify what is not evidence in a science context - **Identify features of investigations that ensure they will result in sound evidence**	

4.1.4 Interpret representations

Several OCS projects provided opportunities for students to interpret representations in the form of graphs. Melissa's Years 5–6 students spent time exploring *The Pieris Project* website and its representations of data in multiple interactive forms, including a map of the world showing where samples originated (with latitude and longitude, the size of the bubble indicating the number of butterflies in the sample), geographical distribution of different genetic groupings, and the most likely direction of invasion. Di's Years 4–6 students explored visual representations of data sets within *Marine Metre Squared*. In another case study, Di's Years 4–6 students recorded and displayed their earthworm counts as graphs and created earthworm life cycles.

Melissa's Years 5–6 students learnt to interpret then create dichotomous keys to classify insects. They then shared their keys with a Year 1 class. Di's Years 4–6 students and Alana's Year 10 students, both classes contributing to *The Great Kiwi Earthworm Survey,* similarly spent time learning to interpret dichotomous keys to help with their earthworm classifications.

Matt and Tanya's *AI4Mars* unit with Years 7–8 students centred on modelling as an example of interpreting representations. The students used "kidBots" (students dressed up as rovers) and "mBots" to model the actions of a Mars rover navigating variable terrain. Students were required in their end-of-unit assessment to describe how the kidBots and mBots had modelled a Mars rover and the issues associated with communicating navigation instructions over large distances. More detail is provided in Section 4.3.1. Here, we emphasise interpreting models as an aspect of interpreting representations.

TABLE 5. **Indicators of progress for interpreting representations**

	NMSSA progress indicators (Aspects demonstrated by case study students are in **bold**)	**Summary of observations about student capability** (Aspects not referenced in the NMSSA progress indicators are underlined)
Level 2		The absence of an indicator for Level 2 from the NMSSA data does not mean that young children cannot interpret representations; indeed, Level 2 achievement objectives in Mathematics and Statistics include gathering, sorting, and displaying category and whole-number data, and comparing the features of simple data displays Years 1–2 students can: - use dichotomous keys Years 4–6 students can: - use classification keys, and use and construct dichotomous keys
Above Level 2	- **Interpret simple graphs, diagrams**, food chains, and **life cycles** - **Use simple science conventions to organise data in graphs and tables**	Years 5–6 students can: - discuss a range of interactive graphical information provided by some OCS projects (e.g., *The Pieris Project*)
Level 4	- **Interpret more formal science representations such as classification keys**, Venn diagrams, and science models - Use science conventions such as arrows in life cycles and food chains - Convert representations of science ideas (e.g., from tables to graphs or words to diagrams)	Years 7–8 students can: - explain how models do and don't represent reality
Above Level 4	- **Distinguish the key ideas in representations** - Use a range of science conventions including units of measurement - **Construct more complex science representations,** such as food webs and diagrams showing forces	

4.1.5 Engage with science

This SC "requires students to use the other capabilities to engage with science in 'real life' contexts. It involves students taking an interest in science issues, participating in discussions about science and at times taking action" (MoE, n.d.b). Our research suggests that teachers may be unclear about the intent of this SC. For example, several teachers identified "engage with science" as a learning outcome for activities that involved hands-on science investigations. We argue that the intent of this capability runs deeper than carrying out a science activity. We also suspect that by encouraging teacher-researchers to focus on one or two science capabilities, opportunities were missed for bringing the capabilities together in the SC engage with science.

Despite these challenges, the research provided evidence that young children are able to identify actions they can take in response to a science issue (see Table 6). For example, Di's Years 5–6 students identified the invasive seaweed species *Undaria pinnatafida* and recognised how it negatively affects the local seaweed ecosystems—leading them to removing it when they found it.

In some cases, contributing to an OCS project can be an example of how students can take action in response to an issue. An example is provided in Carol's Years 5–6 unit Kelp helps! where students learnt about the role of seaweed in the carbon cycle and how seaweed can help to mitigate climate change by acting as a carbon sink. In addition to visiting local beaches to learn to identify seaweeds, the students "took action" by contributing to the OCS *Floating Forests*. This project invites participants to identify kelp forests in satellite images of the ocean, enabling widespread data collection and longitudinal change. The project team had an online discussion with the students, and uploaded satellite images of the Wellington region, helping students to feel their contribution was even more relevant.

TABLE 6. **Indicators of progress for engaging with science**

	NMSSA progress indicators (Aspects demonstrated by case study students are in **bold**)	**Summary of observations about Carol's Years 5–6 student capability** (Aspects not referenced in the NMSSA progress indicators are <u>underlined</u>)
Level 2		- The absence of an indicator for Level 2 from the NMSSA data does not mean that young children cannot engage with science. However, no case studies in our research specifically focused on this science capability with young children
Above Level 2		Years 5–6 students can: - <u>use their growing science knowledge when considering issues of concern to them</u> (Level 3 AO, Nature of Science strand, *NZC*) - <u>identify actions they can take in response to a scientific issue</u> - explain <u>impacts of actions</u>
Level 4	- **Recognise and explain a science issue** - Suggest one side of an argument for a science issue	
Above Level 4	- **Identify and justify an action to address a science issue** - Identify both sides of an argument for a science issue - **Explain why an action has a particular impact**	

4.1.6 Implications: Teaching for science capability development

The findings demonstrate that students who are provided with intentional, appropriately scaffolded and explicit opportunities to develop and recognise the SCs are able to achieve at higher levels than those suggested by the NMSSA progress indicators. This raises concerns that the NMSSA progress indicators may limit learning if teachers interpret them as indicating what students can and cannot do at different levels, rather than suggesting what next steps might be for students, and how learning might be further supported. Our research particularly addresses the current gaps in the NMSSA progress indicators, which are blank for three of the five SC at Level 2, and one SC at above Level 2. While this is because no NMSSA data related to these capabilities and levels, we are aware that some teachers and professional learning providers interpret the absence of NMSSA progress indicators as being indicative that young students are not capable of, for example, critiquing evidence, interpreting representations, and engaging with science—potentially leading teachers to underestimate the complexity that students can grapple with, and restricting the learning opportunities they provide. Our research provides empirical evidence that young students working at Level 2 are capable of interpreting representations. Unfortunately, no case studies in our research specifically focused on young children's ability to critique evidence or engage with science. At higher curriculum levels, our findings indicate that students are also able to exceed the expectations set by the NMSSA progress indicators when they are provided with appropriate learning opportunities. As noted in Section 2.1, the NMSSA data were analysed for science capability progress indicators in the absence of data about how much teaching had occurred in relation to each SC.

Second, our findings highlight the interwoven nature of the SCs. While there were strengths in focusing on one or two capabilities, the case study interventions invariably also included learning that supported development in the other SCs. We also draw attention to the ongoing need for teachers to develop a shared understanding of the intent of the SC engage with science.

The NMSSA progress indicators suggest that progress within an SC is marked by its use in increasingly unfamiliar contexts. Our research demonstrated that the contexts for learning were often not, initially, familiar for students; they became familiar as the teacher implemented the unit. This was even true for contexts that might have been considered familiar, such as the rocky shore. This supports findings from the NMSSA data showing a moderately strong correlation between students' science knowledge and their capability development (EARU & NZCER, 2019). We noted that older students were more likely to have a more extensive "library of experiences" (Bull, 2010, p. 2) to draw on when asked in focus group discussions to give examples of where they had, for example, collected scientific information (gather data) or interpreted graphs that show science information (interpret representations).

We found that participating teacher-researchers who had sound understanding of the science capabilities were prepared to include an OCS that involved complex science practices, and that they designed experiences enabling students to understand and engage with the OCS. In many cases, the OCS project provided the impetus for the nature and rigour of SC development. Repeated opportunities for practice and discussion were key components supporting students' learning, with strategic, intentional questioning and scaffolding by the teacher.

4.2 Affordances of learning through OCS participation for integrating science and DT

In conceptualising this research, our team recognised that the digital nature of OCS projects provided opportunities for teachers to support the development of students' digital literacy alongside, and in addition to, students' SC development. We recognised that, as the DT POs were newly released, there was opportunity for the teacher-researchers to innovate in their practice, and for us to work collectively to develop insights that would be useful to others who were exploring science-DT integration. Our research question therefore focused our attention on ways in which science and DT could be integrated: *How does participating in online citizen science (OCS) projects contribute to the digital technology (DT) progress outcomes newly introduced into NZC?*

Key to DT progress was the integration of explicit opportunities for DT learning within the wider units. Our findings highlight that the OCS project that the teacher-researchers selected to use for each of their interventions acted as a fulcrum for the flow of the unit, and teachers planned DT learning episodes that formed a meaningful aspect within the unit.

What became apparent through the interventions was the various ways in which science and DT could be integrated to support students' learning in both curriculum areas. Cross-case analysis helped us to identify a heuristic of four models for science-DT curriculum integration. Preliminary versions of the models were shared, tested, and refined with the wider team. Below, we introduce the models, each illustrated by a representative case study. Participation in the project's community of practice also had an impact on how teachers integrated DT into their intervention units.

4.2.1 Science and DT taught separately and then combined in a digital output (DDDO)

The first model for integrating science and DT is to teach them separately and then combine the learning in the creation of a final product. An example is Di's earthworm unit, experienced by Years 3–6 students. To contribute to *The Great Kiwi Earthworm Survey*, students had to learn about data collection protocols, then use these protocols to collect, classify, and count earthworms in different locations. Separately, they spent a day at the education centre of Te Papa Tongarewa Museum of New Zealand, where they developed DT skills, such as using green screens, stop motion animations, and *Scratch*. The unit culminated in students developing a digital artefact that enabled them to share their learning about earthworms. This took a range of forms, including short videos and digital objects created using *Scratch*. Our post-observation survey revealed that students specifically enjoyed the DT element of the science unit as it, in the words of one student, "helped me to share my ideas".

4.2.2 Science is foregrounded, and DT showcases science learning

In the second model, science and DT are again combined in a digital output, but DT skills are also used as an integral part of the unit. As with the first model, the science learning is foregrounded, and digital skills are developed when needed in order to support the assessment tasks. The example of this model is demonstrated by Richie's second iteration of a unit "Can humans live on Mars?", experienced by his Year 9 students. The focus for the astronomy unit was using evidence to support a response to the inquiry question: Can humans live on Mars? The OCS project that was integrated into the unit was *Planet Four.*

To support the focus on using evidence, students uploaded summaries of each lesson's learning into their own website using a format in which they recorded evidence surfaced during the lesson that responded to the unit's inquiry focus. Additionally, students created short videos at the end of the unit in which they used sock puppets in a TV game show format to share their learning through storytelling. Both these examples for representing learning—building a website and creating a video—contribute to DDDO progress outcome 3 (Level 5). The potential to broaden the opportunities for explicit DT learning through the unit was noted by Richie; limitations on teaching time mean that teachers intentionally decide which learning opportunities to foreground. Richie's focus on the science is evident in this written reflection:

> The students enjoyed making the videos, but by far the hardest part was writing the scripts beforehand. I was quite hardline on this (we spent two full lessons—2 hours) because I wanted to ensure that the students included as much of their science understanding within their videos as possible rather than it turning into just a fun video-making lesson.

4.2.3 Science provides the context for DT

In the third model, DT learning is foregrounded, with science learning used to "set the scene" and provide the authentic context for the DT learning. This is exemplified by Matt and Tanya's "Mars rover" with their Years 7–8 class. The OCS project, *AI4Mars*, is informing neural network models guiding terrain navigation of Mars rovers. Matt and Tanya introduced the unit with students brainstorming what they already know about Mars, and then providing additional information about Mars and the history of Mars landers and rovers.

The vast distance between Mars and Earth was simulated using a "kidBot" or "kBot": a child in one classroom, dressed as a robot. Instructions were relayed to the kBot using a microphone, and a computer and its camera, modified with a time-delay app, enabled children in the second classroom ("mission control") to see the impacts of the delay. This led to discussion about *AI4Mars* and why rovers need to be able to be programmed to autonomously navigate varying terrain. Next, students used a set of mBots to develop their CT thinking, learning to program the mBots to sense and respond to specific "terrain", simulated by obstacles placed in the school hall. This required students to create and debug programs, and then develop their coding through the addition of loops and iteration (CT progress outcome 3, Level 4). The unit concluded with presentations in which students created slideshows with voice recordings to share their learning (a digital outcome), including how the mBot coding was a model for a Mars rover (see Doyle et al., 2023).

4.2.4 Science and DT taught alongside each other

The fourth model for science-DT integration requires science and DT learning to be taught at various points through the unit. An example of this is Melissa's unit, "Who's eating our cabbages", in which her Years 5–6 students buddied up with a Years 1–2 class to learn about insect classification. The context for the senior students' learning was the OCS project, *The Pieris Project*. When planning for the unit, discussions within the research team inspired the use of dichotomous keys as a context for developing students' algorithmic thinking. During the unit, Melissa made explicit links between the science and DT when the senior students first worked to develop dichotomous keys to categorise insects, using an unplugged context with a range of insects provided on image cards. These students then used the *Visme* app to create a digital dichotomous key for insect classification that they shared with their junior buddies. This activity supported both the CT and DDDO aspects of the technology curriculum for the Years 5–6 students, as well as contributing directly to the science learning for both the senior and junior students. Later, the senior students used what they had learnt about moths and butterflies to think about the adaptations of the cabbage butterfly, which led into exploring *The Pieris Project* website. This required a degree of digital fluency—making decisions about how to navigate the website independently—and provided further opportunities for interpreting representations.

4.2.5 Implications for practice

The findings above introduce four models for integrating science and DT learning. We hope that these models might support other teachers to think about where—and why—they might plan for integrating DT with other learning areas. A further important finding is the value of being part of a community of practice when implementing curriculum innovations. With the DT learning area only having been released in 2017 and mandated for implementation in 2020, our teacher-researchers were still grappling with what DT teaching and learning might look like in their classrooms. As they did this, inspiration from others within the project's community of practice was deeply valued. This is evident in the following teacher-researcher response to a survey question "How has participating in this project influenced your professional practice?":

> My DT skills are still developing but the OCS projects bring a wonderful opportunity to use cross curricular teaching in an innovative way with support from experts in the field. Being able to have support in both planning and implementation of units and developing a close-knit group of teachers who can support each other and […] reflect about the positive and negative aspects of the projects.
>
> The project has raised my awareness of the DT curriculum and I think more about the outcomes of this curriculum and how they fit with science […] I am inspired by listening to the reflections of other teachers and researchers and it is motivating for me to think about how I can innovate in my practice.

A further outcome from the project was teacher-researchers developing their ability to support the professional learning of colleagues beyond the project:

> Now that I am in a school leadership role, the main lasting impact will be on my ability to upskill other teachers in DT and science.
>
> I know that other teachers at school were interested in what I was doing and that this is something I see will be possible to do as a syndicate next year.

In other words, participating in COPs can support teachers in their own practice, as well as grow their leadership potential.

4.3 Human–computer interactions and the impacts of teachers' practices

Given the digital nature of OCS projects, our third research strand investigated: What influences teachers' practices when students use devices, and what is the impact of these practices?

4.3.1 HCI considerations when students contribute to an OCS project

Across the 16 interventions, teacher-researchers used a range of practices with HCI implications. These practices were dictated at times by the number and types of digital devices that were available, and students' prior experience using the devices. For example, some schools had 1:1 device availability and a variety of devices available, whereas other schools had more limited access to devices. From a software perspective, some schools used digital platforms such as Google Classroom. From an OCS perspective, teachers were constrained by the types of projects available, what the projects required of participants, and the level of information and opportunities for digital connection provided by each project. Teachers also took advantage of some of the findings of our previous project; for example, that sharing devices amongst groups may be more beneficial for supporting peer talk (Pierson et al., 2020). Because of this, teachers did not feel limited by the number of devices they had access to—they recognised the value of sharing devices to encourage collaboration. It is important to note, however, that the citizen scientist contribution to the OCS projects is generally not designed to be collaborative—it was the teacher practices that led to student collaboration. Further, encouraging students to work together when contributing to the OCS projects opened up opportunities for SC learning; for example, conversations about the consistency of data interpretation when students working together disagreed about what an image in an OCS was displaying. Our observations also indicated that, when students were sharing devices, they tended to stay more focused on the OCS tasks, and there were fewer exit actions (i.e., going to other websites).

Another important finding relates to the role of the teacher in scaffolding students' understanding of many of the OCS projects and the skills they needed to develop to contribute. For example, Di found that her students needed explicit teaching about how to obtain specific location data from Google Maps so that they could enter this into *Marine Metre Squared*. Section 4.2 above includes a number of other examples where DT skills needed to be explicitly taught as part of the wider intervention units. In some cases, in-class modelling of aspects of the OCS project was important to help students understand what they were seeing in OCS projects that ask participants to interpret photographic or numerical data. For example, Richie's Year 9 students modelled the impact of wind on geyser patterns in class and this helped them to better understand the project images they were asked to interpret in *Planet Four* (see Buntting et al., 2022).

In general, OCS projects that meaningfully support student engagement have clear instructions describing what participants are required to do, a clearly articulated purpose for the project that students can identify with, opportunities for students to work with their own and/or others' data (e.g., *Marine Metre Squared*, *The Pieris Project*), and opportunities to engage directly with the OCS project team. Where projects identified project personnel, teachers often contacted the scientists and students were able to meet with the scientist online. This enhanced their understanding of the project and their enthusiasm for contributing to it, both during class time and beyond. Again, this led to further opportunities for SC development. Together, these design aspects have implications for the OCS project designers—different projects provide different levels of supporting information, tutorials, post-project data insights, and opportunities to engage with the project team.

Finally, the opportunities for teachers to develop their own competence and confidence using digital technologies was enhanced by being part of the project's CoP, as noted in Section 4.2.6. The distance (home) learning precipitated by the COVID-19 lockdowns further enhanced teachers' DT skills, and working with six teacher-researchers we demonstrated that collegial connections are important, and that safe-to-fail environments support innovation (Doyle et al., 2021).

Throughout the research, teacher-researchers noted the shift in power that is associated with positioning themselves as learners in relation to DT. For example, a number of teachers incorporated activities using *Scratch* into their intervention units. Because students in their classes had different levels of experience and expertise working with *Scratch*, a number of scenarios emerged: students using *Scratch* tutorials; students teaching each other (and often the teacher); and just-in-time learning rather than just-in-case learning.

4.3.2 Implications for practice

Overall, we found that teacher planning was important to build in sufficient opportunities for students to learn the specific skills that are needed to engage with digital devices, including hardware and software. Sometimes, teacher-researchers overestimated their students' abilities, and additional opportunities needed to be provided for explicit teaching—sometimes by the teacher, often by other students. Teacher-researchers grew increasingly comfortable with their own positioning in these spaces. They also brought an increasing critique to the value of different OCS projects for supporting students' learning. Part of this critique was associated with the HCI affordances offered by the OCS project; for example, whether data could be easily uploaded, and—in cases where images are provided by the OCS project for citizen scientists to analyse—whether the images are reasonably easy to interpret, whilst being sufficiently engaging. Another important factor affecting teachers' choice of an OCS project was whether the project was likely to remain active for the duration of the teaching unit. Finally, our findings highlighted that student behaviour when using digital devices required ongoing support and active monitoring. Many of our teacher-researchers were adept at offering several learning opportunities simultaneously, providing students with a degree of choice, agency, and flexibility depending on the students' DT skills and interests.

5. Concluding thoughts

This research project was ambitious in scope, investigating three interwoven research threads over a period of 3 years. The project was underpinned throughout by a co-constructive partnership and the emergence of a CoP that valued the expertise of each contributor, enabled teaching and research innovation, and brought different "lenses" to a shared purpose (Buntting et al., 2020). Our intention from the outset was to contribute insights to how teachers can support students to make progress in both the science capabilities and in DT. Since beginning the project, MoE has begun an extensive "curriculum refresh". Already, several of the case studies emerging from the project have been used to inform the science learning refresh and what students might be reasonably expected to "do" at the five different phases of the new understand–know–do framework within *Te Mātaiaho* (Aitken & Wood, 2023). Our hope is that existing and future publications and case studies that emerge from this work will inspire other teachers to develop innovative, engaging science and DT learning opportunities that are appropriately scaffolded *and* that are appropriately complex and challenging.

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