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Elementary students learning through data analysis and sharing findings: design-based research for community and citizen science in schools

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ABSTRACT
While citizen science and other participatory approaches to science are increasingly used in schools to promote student science learning, rarely are these students supported to collect, analyze, and share their data with meaningful outside audiences. In this study, we used a Design-Based Research approach to iteratively develop and examine an elementary school-focused community and citizen science (CCS) program that facilitated students' collecting, analyzing, and sharing forest health data with their forest manager community partners in an area of California, USA facing continual risk of catastrophic wildfires. Focusing on the classes of 3 participating teachers, we observed six classes of 3rd and 4th graders over two 1-year iterations, repeatedly observing their Forest Investigations and class visits facilitated by the watershed educators and interviewing 34 students each year at the end of the program. Our findings suggest that educators and CCS practitioners aiming to support students' development of science knowledge, practices, identity, and agency to tackle local environmental problems should design rich and repeated scaffolded experiences with data analysis and sharing their findings with science partners who can act on their findings.

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Community and citizen science; design-based research; data life cycle

Introduction

Citizen science, community science, and other participatory approaches to science research and environmental monitoring have been increasingly recognized as a valuable educational experience for young people, in and out of school (Kali et al., 2023; Kelemen-Finan et al., 2018; Roche et al., 2020). While there are ongoing debates about terminology in this field (Cooper et al., 2021; Eitzel et al., 2017; Shirk et al., 2012), we here use the term Community and Citizen Science (CCS) to acknowledge the range of participatory science projects that members of the public take part in, from scientist-driven citizen science projects to community-driven community science projects (Ballard et al., 2017). Many have noted overlapping goals of formal science education and CCS (Kali et al., 2023; Solé et al., 2024), and research has shown how participating in CCS projects can support student disciplinary knowledge learning (Kelemen-Finan et al., 2018), science identity development, and agency with environmental advocacy (Ballard et al., 2017). Understanding the

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pathways between CCS and formal science education is an essential avenue of research to better support science education that is based on authentic science practices and connects students to scientists.

Our development and study of the school-focused forest monitoring program, Our Forests (OF), aimed to explore such intersections. Recognizing that many CCS programs only offer opportunities to collect data (Phillips et al., 2021), OF supported students' engagement through the entire 'data life cycle' (Bird et al., 2023), where students collected, analyzed, and shared data on local forest health. We used a design-based research (DBR) approach to iteratively design successive years of programming to support student engagement, learning, and effective pedagogy. While DBR is a well-established approach to studying formal education (Bell, 2004; Brown, 1992; Sandoval, 2014), research in CCS that uses a DBR approach is rare. As suggested by the Committee on Designing Citizen Science to Support Science Learning (NASEM, 2018), it offers a unique opportunity to learn from and systematically improve, comparing the impacts of activities and program structures between iterations through teacher feedback, student data, and observations.

In this study, we aimed to understand how the OF design features (DF) evolved and their impact on student learning. OF was designed around three main DF focused on supporting students to engage in: (1) Place-based Data Collection, (2) Data analysis and meaning-making, and (3) Sharing Findings with Community Partners. While place-based data collection is often the only feature included in many CCS projects and, thus, well-studied, we instead focus on students engaging in data analysis and sharing findings, which are much less well-studied features, aiming to understand how changes in these areas impacted student Environmental Science Agency (ESA) development. ESA is a measure that prioritizes disciplinary science knowledge and youth development of identity and agency with science as the key learning outcomes we seek to observe. In this study, we asked the overarching question: *How did the design of the Our Forests program, focused on scaffolding/facilitating elementary students' data analysis and sharing their findings with a community partner, impact students' development of Environmental Science Agency*? To guide our analysis, we asked two sub-questions: What changes did the design team make to scaffold/facilitate students' data analysis and sharing findings with community partners? How did those changes impact participating elementary students' development of ESA?

Background literature

CCS at school

As scientific literacy is a significant goal of formal education, and with the shift of defining science literacy from an individual effort to a collective and collaborative endeavour, there's a need to rethink how scientific knowledge and practices are taught, generated, distributed, and learned. One approach to support these goals is through community and citizen science (CCS), achieved by allowing students to conduct authentic science inquiry, communicate with scientists, contribute directly to scientific research, and support their own everyday meaning-making processes (Bonney et al., 2009; Roche et al., 2020). Data literacy skills are supported by exploring the data to develop inquiry questions and applying the analysis to real problems, which can lead to a more in-depth understanding of the content knowledge and data understanding (Kjelvik & Schultheis, 2019).

However, bringing CCS to schools also faces certain challenges. CCS projects for K-12 schools often include multiple stakeholders, and it can be difficult to integrate their differing objectives, for example: scientific goals and learning outcomes (Harlin et al., 2018; Roche et al., 2020). A systematic review of 46 papers reporting on Citizen Science (CS) in schools revealed that only 20% of papers portrayed students as scientists when participating in the CS programs, and only 37% reported engaging students in science learning through data collection (Solé et al., 2024). This lack of full engagement in the 'data lifecycle' was highlighted as an area needing improvement to support student learning and science identity development.

Data life cycle in CCS

Many CCS programs focus mainly on engaging participants in the data collection phase and seldom go beyond including other scientific research phases. To truly tap into CCS's educational potential to support science literacy development, we need to ask participants for more than just data collection and also engage them in their own learning and knowledge generation processes. Bird et al. (2023) refer to the approach of engaging students in the entire scientific research cycle as engaging students in a 'data lifecycle.'

Data analysis as a way to support data literacy

Engaging students in full data-driven scientific inquiry also coincides with another strand of educational research effort – data literacy. Data literacy is generally considered an important skill that people should acquire in a society that increasingly relies on big and complex data to make decisions (Wolff et al., 2019). Given that many scientific practices in a CCS program are data-driven practices (Gibson & Mourad, 2018; Kjelvik & Schultheis, 2019) and often mirror many science standards (Germann & Aram, 1996; NGSS, 2013), there is great potential for supporting data literacy through CCS in schools. Student data literacy has been shown to improve when given opportunities to interact with and analyze authentic data, such as that collected through CCS (Gould et al., 2014; Kastens et al., 2015). A CCS program in a school that generates authentic, place-based data that connects to the students' real-world context and provides a practical application of the data can help make connections to disciplinary content and support an increased emotional connection to data for students (Doering & Veletsianos, 2007; Langen et al., 2014; Wolff et al., 2016).

Sharing findings to support agency development

Another key component of completing the data lifecycle in a CCS program is connecting students with the scientist, community organization, or partner that will utilize the data they have collected. When students do not feel like the data will be used or understand who they are collecting data for, data can begin to feel inauthentic (Harris et al., 2020), and inauthentic data has been found to be more challenging for students to interpret (Piatek-Jimenez et al., 2012). However, when this connection is made clear, and students are able not only to analyze but also share their findings with that scientist, they engage in an important process that can increase self-efficacy in science, science identity, and scientific agency (Ballard et al., 2017; Bird et al., 2023).

DBR and CCS

Design-based Research (DBR) is a research method that uses iterative design approaches to create learning environments, artifacts, services, or programs to advance theory and practice in educational research settings (Brown, 1992; Sandoval, 2014). Though the DBR approach is not new to the educational research field, it has not yet been widely adopted in the field of CCS, though it is gaining attention (Dibner & Pandya, 2018; Magnussen & Hod, 2023). DBR as an approach certainly parallels Community-Based Participatory Research (CBPR) in the public health field (Israel et al., 2015) and other participatory approaches in the development and natural resources fields (Chambers, 1994; Fortmann & Ballard, 2011) in placing equal value on perspectives of those affected by the problem, in this case, an educational problem, as the perspectives of university researchers. Sandoval (2014) and others have additionally captured the cyclical and iterative nature of these methods by offering models and structures for DBR design cycles that include integrating theoretical and practice experiences to design and implement a program, collect data on that implementation, interpret that data together and re-design to better meet the learning goals for the next iteration.

Theoretical framework

We take a socio-cultural perspective to theorize learning. This study defined learning as an ongoing change of participation in the community (Lave & Wenger, 1991; Rogoff, 2003), which means not merely measuring learning as conceptual changes but understanding how identity develops and how youth exercise agency in their community. Scholars such as Lave and Wenger (1991) and Rogoff (2014) argued that there is a paradigm shift in viewing learning from pure cognitive activities to a cultural practice, and learning needs to be studied within the situations and contexts of the community. As Bell et al. (2017) argued, learners' identity or ideas about themselves mediate their participation within and across learning environments.

We regard identity and agency as fluid, situated, and constructed in practice and in relation to the youth's activities and community. Though identity and agency are two different constructs, they are closely related to and leverage each other in this process. Basu et al. (2009) argued with their critical science agency framework that as learners construct their identities through interaction within communities of practice, the 'process of coming to be' provides opportunities for learners to exercise their agency to alter their environment to become. In this way, developing disciplinary knowledge is another critical step in supporting identity development and exercising agency. For this research, we use the Environmental Science Agency (ESA) framework to conceptualize learning outcomes (Ballard et al., 2017). Specifically, ESA was first framed by Ballard et al. (2017) to include three aspects: (1) the science content knowledge and skills to ensure accurate data production, (2) self-identification with roles within the community of practice, and (3) a sense of agency to apply scientific findings to leverage for change. In the context of CCS, we look for how youth take up/develop the following for each component of ESA:

(1) The 'processes, skills, and modes of inquiry associated with this content' (Basu et al., 2009), in this case, forest ecology content.
(2) Particular roles within their project groups and forest/environmental science more generally, and how youth came to specialize (or not) in different project components (i.e. sharing findings, making graphs, etc.).
(3) A sense of agency for taking action, including how they formulate personal ambitions and goals and imagine and expand their involvement in local environmental issues that impact their lives and community.

Methods

Context

Our Forests (OF) is a four-year collaborative research-practice partnership with the Center for Community and Citizen Science at U.C. Davis, the Sierra Streams Institute (SSI), and the County Office of Education. It engaged 3rd to 5th-grade students in forest health monitoring across Nevada County, California, an area susceptible to and that had recently experienced to catastrophic wildfires, over two implementation years (2021–22 and 2022–23). Students collected, analyzed, and shared local forest ecology data, like tree stand density, ground temperature, downed woody debris cover, and understory diversity, to inform how a community can manage their forests to promote forest health and reduce wildfire risk. Students were prepared to collect forest health data through lessons led by SSI educators, which focused on forest health concepts, building inquiry skills, and reasoning practices. Forest health data was collected during field trips (called Forest Investigations) to local forest sites, which were additionally supported by three to five parent volunteers. In each of their Forest Investigations (FI), students collected data using a modified forestry protocol that involved tools like Biltmore sticks, quadrats, and thermometers. Students gathered both numerical and observational data that they could then analyze. SSI instructors followed curricular sequences

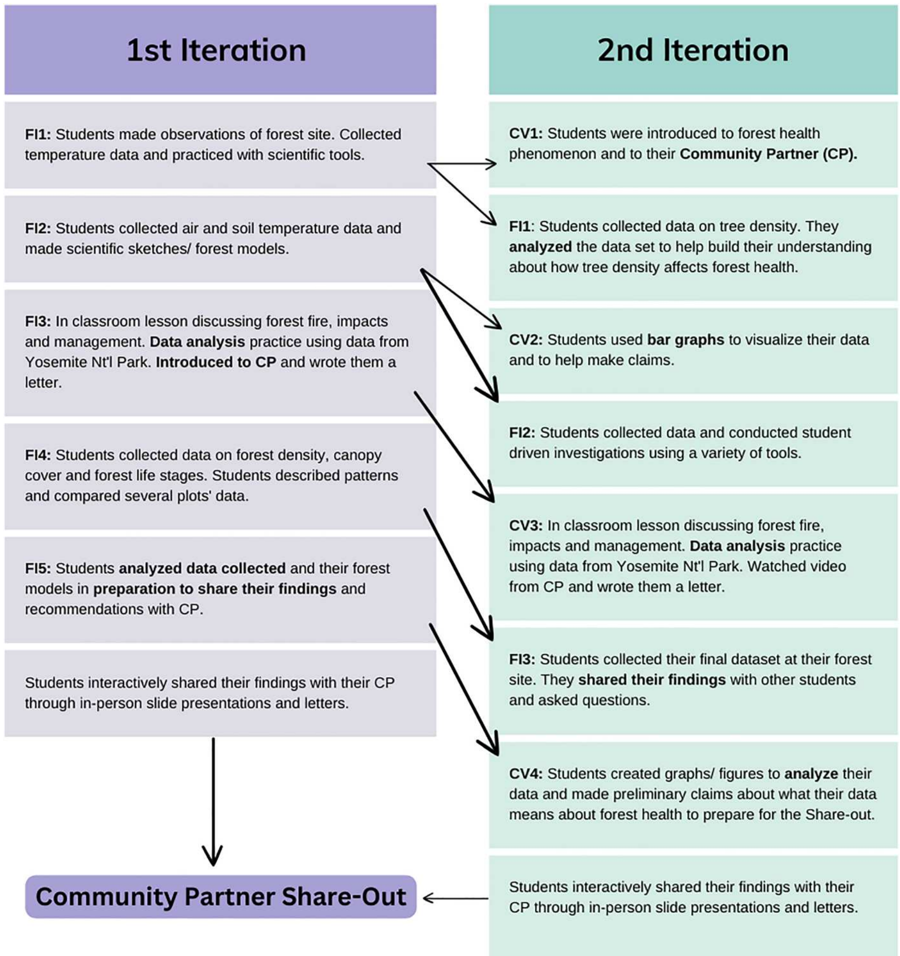

Figure 1. Program Curriculum Sequence for the First and Second Iteration. Arrows indicate how lesson activities shifted between iterations (i.e. FI1 became CV1 and FI1).

very closely, ensuring similar experiences across schools. The structure and sequence of classroom visits (CV) and forest investigations led by SSI educators differed from the first iteration to the second (Figure 1). Students participated in five (in the first iteration) and three (in the second iteration) full-day (4-5 hours) field trips that involved data collection and sensemaking activities related to forest health concepts. Students analyzed their forest health data in the field (in the first iteration) or in the classroom a few days after each field day (in the second iteration) to help contextualize the data and its importance to forest health. OF ended with a *Share-Out* presentation in both iterations, with students sharing their findings with the Community Partners (CP) utilizing their data.

Participants

Participants in the program

To recruit teachers/schools, all 3rd to 5th grade teachers in the district were invited to participate by the superintendent of schools, and all who applied were accepted. We recruited nineteen teachers from four schools for the first iteration and fourteen teachers from four schools, eleven returning for the second. Given the in-depth qualitative data collection methods used, we selected ten focal classes in the first and eight in the second iteration to study more closely. To select the focal classes, we considered the spread of grade levels at each school, charter vs. traditional public schools, the geographic distance between the schools and the field trip sites, and the percentage of students who received free or reduced lunch. For the second iteration, we prioritized choosing the returning focal teachers and teachers with the most returning students from the first iteration.

From each class, we collaborated with teachers to select four to six focal students to observe and interview. We selected a range of students with respect to gender, school performance based on grades, and their responses to a short survey regarding initial interest in and confidence in conducting science, being in nature and experiencing the outdoors. All classes were from a rural county, with 60% of students receiving free and reduced lunch services.

Participants in the study

For this study, we examined data from the classes of three teachers who participated in both iterations: two fourth-grade teachers and one third-grade teacher, representing two schools and six classes of students, or three classes per implementation year. The two schools represent a public and a charter elementary school, with about ∼75% white students, 15% Hispanic, and 10% other/mixed race. We selected returning teachers to mitigate the influence of teacher differences on student learning outcomes. For the first implementation year, five focal youth were selected from each class ($n = 15$). In the second implementation, six focal youth were selected from each class ($n = 18$). Focal students had recent experiences with multiple forest fires, with students mentioning they had to either escape the fires or were otherwise deeply affected. Pre-survey data on student science and nature interest and familial connection to science were similar between the two years of implementation, with most students reporting neutral to positive responses (Table 1). We did not collect any demographic data on the focal students.

Data collection

For this study, we performed interviews with focal students (semi-structured, post-program interviews), students' pre and post-program surveys, and observations of focal students engaged in the Our Forests Curriculum (structured field notes during all focal students' field investigations and most classroom activities led by SSI educators). The interviews explored students' ESA development and lived experiences of collecting and analyzing data and sharing findings with a community partner. These lasted approximately 30 minutes each and were conducted just outside the classroom no more than two weeks after the final Share-Out session. For the pre and post-program surveys, we used a 4-level Likert scale survey instrument to capture students' science interests, nature interests, and Environmental Science Agency (ESA), which included a series of open-ended questions for students to provide further description to their responses (see Appendix 1). For the observational notes, the researchers followed the focal students in each class and, using a template, wrote detailed descriptions of how focal students engaged in the activities and their personal reflections on what

Table 1. Averages for responses to Likert-scale (1-NO! to 4-YES!) survey questions assessing science and nature interest, and familial connection to science.

Survey Question	Year 1 Average	Year 2 Average
The people who care for me and I enjoy being in nature together.	3.21	3.30
The people who care for me are interested in science.	2.77	2.79
I like to learn about nature, like which animals live in forests or how plants grow.	3.32	3.38
I like to learn about science in different ways like reading science books, watching videos, drawing science diagrams or talking about science.	3.04	3.04
I like to spend time exploring our local forests.	3.28	3.27
Science is my favorite subject in school.	2.82	2.65

they observed (see Appendix 2). To ensure we observed each focal student for approximately the same amount of time, we rotated the observations to different focal students every 15–20 minutes. In the second iteration year, we additionally collected video data of all focal classes' field trips and in-class activities led by SSI educators. We continued taking in-the-moment field notes during observations, but we also reviewed videos after the field trips to include more details in the notes. For this study, we collected a total of 37 field notes, 5 sessions per class for the first iteration and 7–8 sessions per class for the second iteration.

DBR conjectures and resulting curricular changes

OF was designed to achieve multiple learning objectives using the three design features (collecting, analyzing, and sharing data) as a curricular framework. These included increased knowledge of core ecological concepts, engagement in scientific practices and skills, and opportunities to build relationships with professional forest ecologists and land managers. During and after each implementation year, program collaborators (SSI educators, UCD researchers, Community Partners, and teachers) evaluated the program to see if and how objectives were met through surveys, conversations, and facilitated group discussions. Through this evaluation, the curriculum underwent two DBR cycles, which we refer to as the first and second iterations.

Drawing from Sandoval (2014), we utilized DBR conjecture mapping as a 'means of specifying theoretically salient features of a learning environment design and mapping out how they are predicted to work together to produce desired outcomes' (pg. 19). Conjecture mapping allowed us to be specific about the principles and theories we wished to guide the program, including our design features and ESA. Sandoval highlights that conjectures can be embodied in four kinds of elements (defined in Table 2) in the program design: (1) Tools and Materials, (2) Task Structures, (3) Participant Structures, and (4) Discursive Practices. By examining these embodiments, we explored the learning that was mediated through these elements and, by comparing the iterations, understand how impactful the design-based changes were on learning outcomes explored through ESA. In this study, we present the changes that are associated with the design features of 'Data Analysis' and 'Sharing Findings.' A summary of the curriculum associated with the Data Analysis and Sharing Findings features, as described through the embodied conjectures, is described in Table 2.

Data analysis methods

We coded the 33 focal youth interviews and the 37 observational field notes. It is important to note that we did not observe lessons taught by teachers (i.e. the Yosemite data analysis lesson). Interview, open-ended survey questions, and observation data were iteratively coded using themes developed *a priori* to create a codebook (Ballard et al., 2017). In the first stage of analysis, all interview transcripts and observation field notes were uploaded to Dedoose. Three authors independently read and coded these data to identify enactments of two key YCCS Design Features: Youth Engaging in Data Analysis and Youth Sharing Findings with Outside Audiences (Table 3). Authors were mindful during this process that our own biases might limit what we coded as enactments of the Design Features, as it is not uncommon that participants might respond in ways that are not recognized by the program goals. Examples of disengagement or other behaviors, like play, were noted and, while not reported here, examined to support the iterations of the program. Once all the data had been coded, the second stage of analysis began. The first three authors independently read and coded the same data using three parent codes and their child codes designed to identify enactments of ESA focused only on the excerpts that had already been tagged in the first stage of analysis (Table 3).

In the third stage of analysis, Dedoose software was used to generate a spreadsheet of co-occurrences across the two Design Feature parent codes and the three ESA Learning Outcome parent codes; or, in other words, a spreadsheet including all excerpts which were tagged with at least one of the Design Feature codes and at least one of the ESA Learning Outcome codes. Two researchers

Table 2. Summary of Embodiments Dimensions.

DBR Four Embodiment Dimensions and Definitions	Design Feature	First Iteration	Second Iteration
Tools and Materials: 'Tools include software programs, instruments, manipulable materials, media, and other resources (Sandoval, 2014, pg. 22).'	Data Analysis	Students were given a Datasheet with guided questions to analyze the data. Students were given a data graph along with the datasheet to make claims.	Students were either given a data graph to make claims or an empty bar graph to create a hands-on bar graph showing the data from different plots and management statuses.
	Sharing Findings	Students had indirect contact with CPs and teachers leading the preparation and Share-Out session with support from practitioners if requested.	Students had direct contact with CPs, and Powerpoint templates provided to students and teachers to gather information for Share-Outs.
Task structure: ' The structure of the tasks learners are expected to do – their goals, criteria, standards, and so on (Sandoval, 2014, pg. 22).'	Data Analysis	Students filled out and read data sheets to make claims in the field investigation.	Students produced a data graph and interpreted the graph to come up with claims in the classroom.
	Sharing Findings	Students got to know their CP and took on roles as responsible scientific presenters/ collaborators; students created Share-Out presentations as a small group.	Students got to know and become known by the CP and take on roles as responsible scientific presenters/ collaborators making effective scientific arguments
Participant structure: 'How participants (e.g. students and teachers) are expected to participate in tasks, the roles and responsibilities participants take on (Sandoval, 2014, pg. 22).'	Data Analysis	Students performed the activities in the group setting.	Students performed the activities individually first and then in the group setting.
	Sharing Findings	Organized students as small group collaborators to prepare for the final Share-Out activity and to create Share-Out presentations.	
Discursive Practices: 'Ways of talking (Sandoval, 2014, pg. 22).'	Data Analysis	Claim – Evidence – Reasoning (CER) Discourse Patterns	CER Discourse Patterns; 'I notice/I wonder' to jot down observations and questions based on the data graph
	Sharing Findings	Facilitators modeled and prompted students to use CER discourse patterns during the brief Share-Out preparation (which was in the field).	Facilitators modeled and prompted students to use CER discourse patterns during Share-Out preparation and presentations.

Table 3. Main and sub-codes and definitions for key design features and components of Environmental Science Agency (ESA).

Main Code	Sub-Code	Definition
ESA 1 – Developing Disciplinary Knowledge and Practices (Authors (a), 2017)	ESA 1.1 Scientific knowledge & Environmental Science Content	Focal youth is observed demonstrating or describes engaging in learning new content, adding to their knowledge related to environmental science, including types of trees, facts about the forest, the impact of forest fire, and vocabulary and concepts like diversity, density, and abundance.
	ESA 1.2 Scientific inquiry skills and practices	Focal youth is observed demonstrating or describes engaging in using observational, reasoning, or practice-based skills, evidence, and cause & effect to make sense of the natural, physical, constructed, and social worlds.
ESA 2 – Identifying Areas of Expertise (Authors (a), 2017; Authors (b) 2023)	ESA 2.1 Taking on roles or developing new roles	Focal student is observed demonstrating or describes engaging in moments when they self-identify as specialists or self-select roles in specific data collection or analysis methods.
	ESA 2.2 Becoming competent over their actions and roles	Focal student described or demonstrated becoming competent in learning disciplinary knowledge and using inquiry skills and tools within the project.
	ESA 2.3 Recognized by others or self as an expert in science or specific areas of science	Focal student is observed demonstrating or describes engaging in being recognized by others or at a part of science. Also, when a respondent says they feel like a scientist or identify as someone who does science.
ESA 3 – Enacting ESA (Authors (a), 2017)	ESA 3.1 Shares knowledge/ expertise teaching others	Focal student is observed or mentioned communicating their CCS findings and science practices gained to outside audiences as an act of agencyto educate others or encourage others to get involved and help create change.
	ESA 3.2 Proposing new/alternative questions and solutions for the community	Focal student is observed demonstrating or describing engaging in actions they can take, want to take, or have taken to help with the forest health that will lead to imagine the forest in the way they wish to see based on what they've learned about forest health.
	ESA 3.3 Applying disciplinary knowledge and practices practiced in the project to another context	Focal student is observed demonstrating or describes engaging in how they are engaged with science and they contribute to science voluntarily in their own time when they take an actual action or describe a scenario of using the tools or/and scientific practice learned in the program in another space and time.
Design Features	Youth Engaging in Data Analysis	This includes any moments/episodes when students were guided by the instructors, self-initiated, or referred to make sense of the data, looking for patterns, making claims based on the data.
	Youth Sharing Findings with Outside Audiences	Focal youth is observed demonstrating or describes engaging in explaining or otherwise sharing about OF and the data they collected and analyzed, or any part of the project, with someone other than their own teacher or fellow students. Especially includes any engagement in preparations to and share findings with the CP.

then performed independent open coding (Creswell & Creswell, 2017) of the co-occurrence excerpts responding to these analytic questions: (1) What was the specific nature of the ESA learning occurring in the excerpt? (2) How did or didn't this Design Feature serve as a pathway to ESA learning?

In the fourth stage of analysis, analytic memos were written to summarize and refine the themes and patterns that emerged from open coding relating to specific intersections of Design Features, ESA Learning Outcomes, and program years. Analytic memos responded to the analytic questions from stage three, but also, how did the first iteration and the second iteration data differ with respect to these questions? And what were the key programmatic or curricular events during which this Design Feature and this ESA Learning Outcome were enacted together? Finally, all authors collectively reviewed and discussed the findings represented in analytic memos from both the university researcher and practitioner perspectives. In particular, the practitioner partners could respond to questions about relevant curriculum materials and decisions and share their first-hand experiences as program instructors for reference. This was an important part of the analytic process and a critical member check for validity purposes (Creswell & Creswell, 2017). Specific Likert-scale questions around science and familial interest were averaged across focal youth responses at this stage to triangulate the qualitative data.

Results

We found that across the two iterations: (1) the tools and materials designed for Our Forests (OF) enabled students' ESA development primarily in the areas of competency in data analysis (ESA 2.2), sophisticated use of science and engineering practices (ESA 1.2) and scientific concepts related to forest ecology (ESA 1.1), and some aspects of enacting environmental agency (ESA 3); (2) the task structures primarily influenced ESA development in students feeling competent in constructing and interpreting data representations like graphs (ESA 2.2), comprehension of relevant scientific terms (ESA 1.1), and developed skills in argumentation from evidence (ESA 1.2), (3) the participant structures supported students feeling competent in their skills related to sharing findings and data analysis (ESA 2), and (4) the discursive practices throughout impacted students' development of disciplinary knowledge and science reasoning practices (ESA 1). While we next report the four embodied elements of the design individually, as noted by Sandoval (2014), these are often overlapping and work together to support learning, which we elaborate in the Discussion.

Tools and materials

Overall, learning outcomes related to data analysis and sharing findings in both years included all three aspects of ESA for all students, including using project-related disciplinary terminology and concepts (ESA 1.1), use and/or discussion of scientific practices (ESA 1.2), demonstrating competency or identifying their own expertise in forest sciences (ESA 2.2), and demonstrating agency to enact change for the environment by proposing novel solutions to community environmental problems (ESA 3). Specifically, we found that changes in tools and materials from the first to second iterations related to data analysis enabled several students in the second iteration to demonstrate a more nuanced understanding of the data and an increased sense of competency in data analysis (ESA 2.2) by creating their own graphs of the data. Those related to sharing findings enabled several students in the second iteration to demonstrate a more sophisticated use of science and engineering practices (ESA 1.2), and scientific concepts related to the OF curriculum (ESA 1.1).

In the first iteration, there was one facilitator-led data analysis lesson that occurred during the final forest investigation. We found evidence that the tools and materials here supported many students' comprehension of interpreting graphs, making scientific claims based on data, and a deeper understanding of the concepts the data was conveying (e.g. tree density or plant diversity). In interviews, some students could use their graphs to interpret and explain data collected many months before and described the importance of graphs as a tool to support data comprehension and forest ecology knowledge. For example, Riley, a 4th grader, reflected on using graphs,

> I think this part was pretty fun, actually … we got to learn a lot about what the other groups found. One of the groups had 100% Scotch broom. My group, we had a little too much grass in our area and I don't think that was great; it's too much abundance.

We see here how this student demonstrated disciplinary knowledge (ESA 1.1), such as the term 'abundance' and recognizing that forest data varies among plots.

In the second iteration, multiple classroom-based, facilitator-led data analysis lessons were introduced. As we can see from this excerpt from the classroom discourse during the graphing activity, facilitators guided students through the graphing process, supporting student learning around disciplinary knowledge of graphing (ESA 1.1). '*Badger asked the kids what the horizontal axis was showing. Noah – It tells what the plot is. Badger – What vertical axis is showing? Jordan – Numbers showing. Badger – What are the numbers? Jordan – How many types.*' We see the Facilitator (Badger) scaffolding and supporting the language relevant to the graph (vertical and horizontal axis) and the program goals (measuring forest density). While similar learning outcomes are present in the first iteration, this additional scaffolding and lessons around data analysis supported many students' learning through a more accurate understanding and use of disciplinary knowledge (ESA 1) and increased competence in graphing (ESA 2.2).

In the first iteration, in activities related to students sharing their findings with their community partner (CP), many students demonstrated knowledge and understanding of relevant disciplinary concepts and practices. However, there was room for improvement in how students were scaffolded to prepare and present findings to share with their CPs, and many of the presentations lacked disciplinary authenticity in terms of the questions, claims, evidence, and reasoning that were ultimately shared with CPs. We see this in an interview with Riley, a 4th-grade student in the first implementation year:

> Well, sometimes, Sophia and I would make a slide that said like, 'What do you think our forest will look like in 30 years? If, when we, like, do you think if we took care of it, would it become a tropical forest? Or do you think we don't take care of it and it just turns into a big desert that's no fun?. And my mom had a really good recommendation … that maybe if people turned off their cars while they were waiting for their kids and only turned them back on when they needed to go up … maybe that could help with our forest a little bit too, because of the gas.

This student demonstrated conceptual disciplinary knowledge, understanding of scientific practices (ESA 1) and science agency (ESA 3) by discussing strategies for supporting forest health with people outside of program activities. They also demonstrated discipline-contradicting ideas (e.g. that a pine forest might become a tropical forest if residents 'took good care of it') and claims making (ESA 1).

In the second iteration, facilitators gave more extensive scaffolding and preparation for the Share-Out presentation (e.g. adding language supports and an entire facilitator-led lesson). In the presentations, many students demonstrated sophisticated use of science and engineering practices (ESA 1.2), for example, asking questions, arguing from evidence (e.g. goat grazing might be too expensive), and communicating information. Students also demonstrated more sophisticated use of related disciplinary concepts (ESA 1.1). We can see this in a field note from the Share Out Presentation, in which a group of students shares their findings with their CP, Cameron.

> Edward: The total plant diversity conclusion was that our understory diversity is over 5 times more than our tree diversity and almost 5 times as much as our shrub diversity. We have a lot more understory diversity in the managed plot than the unmanaged plot.
>
> Alex: I have a question for Cameron. Are you clearing up the area where we go to study our forest? Cause of fire hazard, it is very easy for the fire to spread and start there.
>
> Cameron: There will be treating around where you did your investigation. But the unmanaged plot will remain unmanaged. They took a giant machine right at the edge of it.

As compared to the first iteration, students in the second iteration of Share-Out Presentations were more authentic to the discipline, with students engaging in disciplinary practices (e.g. communicating information, asking questions, making claims from evidence, and using mathematical reasoning (ESA 2.2)), demonstrating good understanding of project-related disciplinary concepts (e.g. diversity, understory, fire risk as a function of management practices) and terminology (conclusion, plot, managed and unmanaged, fire hazard) and making suggestions (ESA 3).

Task structures

Overall, in both years, many students grasped the importance of data analysis and were able to use data visualizations to understand their data (ESA 1) (e.g. density of the forest). Students collaborating with peers to share their investigation findings enabled them to argue from evidence, communicate information (SEPs / ESA 1.2), and use disciplinary concepts and terminology (ESA 1.1) in talk and writing. Changes between the iterations related to task structures of data analysis included a shift in the number of activities, the addition of individual practice in graph making, and the organization of data collection and analysis from a single plot to managed vs. unmanaged plots. The majority of students in the second iteration discussed the feeling of expertise they developed by learning to graph (ESA 2.2) and demonstrated increased comprehension of relevant scientific terms (ESA 1). Changes in task structures related to sharing findings with outside audiences enabled some students to demonstrate sophisticated use of developing an argument from evidence (ESA 1.2).

In the first iteration, students only had one opportunity to analyze data with facilitators, students working to connect the data they collected to the graphs generated by the facilitators. This activity was beneficial for student disciplinary knowledge (ESA 1.1), as they connected their previous data collection activities to the ecological measures they aimed to understand, e.g. density and abundance. This excerpt shows that a Facilitator prompts students to reflect on how their plots have changed.

> Facilitator: If you were to make a hypothesis or guess about which plot has more diversity, what would you say? Sophia: We have a little more because where we did it last it has grown a little more. There are more plants.

This student correctly describes what it means for the plot to increase in diversity (ESA 1.1).

In the second iteration, students had three opportunities, including one independent graphing activity, to engage in data analysis. In the interviews, students demonstrated increased process-oriented skills (ESA 1.2), such as more detailed descriptions of how they made the graph. They better understood and described the nuanced differences between making the graph and reading a graph handed to them. Related to this, students discussed how they overcame the challenges of creating their own graphs. We see this here with Edward, a 4th grader,

> Interviewer: So this [making the graph] is harder than looking at the graph.
> Edward: Yes. It was way harder. I mean ‘cause you had to actually color it and draw it out. That one, the bars were there, you just had to count them up. But this one, you have to color it up. And if you go over a little bit, it might seem like it’s four.

This student described the challenges of creating a graph, like accurately filling the bars to represent the correct number. They relate to the ease of just reading a graph, where one only has to count to where the bar is. However, while this was a challenge, a few students described how this and other data analysis processes became easier, as we see here from Annie, a 4th grader, who initially struggled with understanding how to read a graph but with practice, figured it out,

> Annie: Um … Well, I didn’t really know what it [the graph meant] meant. Like, I was always really confused. I thought it was how tall the tree was.
> Interviewer: But now you’re just like, this [the graph] is [represents]the number of trees.
> Annie: Yeah.

This showcases the importance of repetitive data analysis practice in supporting student learning (ESA 1) and competence in data analysis (ESA 2).

In end of program student interviews, in both years, many students referenced data analysis (graphs, etc.) as a key activity that made them feel like they were scientists (ESA 2). We see this here in a 4th-grade student:

> Interviewer: So, did any activity make you feel like a scientist or like you were doing science?

Ashley: Maybe, like, when we're making the charts, because it kind of- When we're charting, kind of make me feel like we are, like, making … we're making something. And we didn't know … we didn't know what we were doing, but at the same time, we did it. So, that's kind of like science.

While this was present in both years, with the increased exposure to data analysis activities in the second iteration of the program, we found a stronger connection between data analysis and science identity in the focal students. This also reflects an expansion of students' views of science, as in pre-survey responses, students largely mention science as involving experiments, observation, and knowledge generation, none discussing data analysis as part of this process.

In the first iteration, students collaborated with peers to create Share-Out presentations in small group activities facilitated by their teachers. We see this here in an observation note from a presentation in a 4th-grade classroom.

> The students show the graph of their data. They talk about how they used quadrats to count the 'diversity and abundance' of plants in the area. They also provide definitions for these terms. They also review 'density' and how that can impact a fire's movement. They talk about controlled burns and scotch broom. Their recommendations include don't start fires, pull scotch broom when they go on walks (from the roots), pick up plastic to not pollute the ocean, plant new trees in open spaces.

In this example, students communicate data (their graph) and make recommendations (e.g. not start fires). However, the recommendations are not specifically related to the data, and no scientific reasoning is provided.

In the second iteration, students collaborated with peers to create Share-Out presentations in small group activities facilitated and scaffolded by OF facilitators. This, in turn, supported students' ability to create presentations based on data and students' making claims based on evidence. Here, we see an observation from the Share-Out presentation in the same classroom in the second iteration.

Eloise: We found our managed plot has a lot more plant diversity. The unmanaged plot does not have as many as the managed plot.
Mariam: Based on our data, our managed and unmanaged plots are different because the managed plot is higher than the unmanaged plot.
Eloise: The reason that might explain this is that the unmanaged plot has more woody and less non-woody. The unmanaged plot has 1 digit number, less room to grow in the understory. The understory is getting shaded out.

In this example, students communicate their findings as supported by their data, providing evidence to support their reasoning. They also exhibit effective use of disciplinary terminology (ESA 1.1) and an understanding of their data as it relates to forest health (ESA 1.2).

Participant structures

In both iterations, participant structures were arranged in small groups for data analysis and sharing findings. In the second iteration, students' small groups were better scaffolded in the Share-Out preparation and data analysis activities included one in which students worked individually on creating graphs of their data, supporting ESA 2 development.

Participant structures related to data analysis organized students in small groups with whole group discussions for both years. Small group discussions of making sense of data visualizations supported the development of scientific argumentation, with students having to defend their claims based on data (ESA 1.1). This was particularly supported through the multiple iterations of data analysis practice in the second iteration, as we see here in the second data analysis activity, occurring in a 4th-grade classroom.

Mary: I think that managed and unmanaged are similar, not unsimilar. Because managed has more shrubs but unmanaged has no shrubs.
Ashley: But there's more shrubs in the managed than in unmanaged.
Edward: True.

Badger: So more total shrubs.
Edward: But we are talking about diversity.
Will: We all disagree. We all agree they are different but different reasons.

The students in this group are trying to decide whether the managed or the unmanaged plot has more diversity. They use the graphs provided, their experiences in the field, and disciplinary knowledge to support their claims.

In both years, participant structures related to sharing findings organized students as small group collaborators to prepare for the final Share-Out activity and to create Share-Out presentations. In the second iteration, small group work was better scaffolded and supported, which enabled students to develop roles (in some cases) like 'artist' and 'CEO,' as evidenced in interview data.

Interviewer: I heard that, you were the artist.
Rose: (laughs) Yeah, I did all the pine cones, and I glued these pencils for that tree there.
Interviewer: That's really cool. So I also heard that while you were doing this your team decided to name, different roles, like Captain, and-
Rose: Mm-hmm. There was the CEO. Edward was the co-manager. So that was just basically, like, we asked him what we needed to do and what was important. So Liberty, Edward and Alex, wrote all the paragraph that we wrote down and stuff that we learned.

We see how this student recounts the process of creating the Share-out presentation. With additional time and scaffolding, the small group structure allowed students to be creative and take on identities while creating the presentation poster (ESA 2).

Discursive practices

In both iterations, students were guided to use Claim – Evidence – Reasoning (CER) Discourse Patterns when engaging in data analysis and sharing their findings, which supported student meaning-making and engagement in disciplinary knowledge and science reasoning practices directly and repeatedly (ESA 1).

CER discursive practices were used in both iterations to support the data analysis activities that happened collaboratively during the forest investigation. These activities supported disciplinary content and skills development (ESA 1), like scientific argumentation. In the second iteration, students were also encouraged to use the sentence frames of 'I notice' and 'I wonder' when making sense of data. While parts of this were challenging for some students, we found that struggling through it supported their comprehension of graphs (ESA 1) and feelings of competence in this new skill (ESA 2), like Will, a fourth grader, stated explicitly in their interview.

Will: Well, I think for the graph, the 'I wonder and I notice … ' is the hardest part because 'I wonder … ,' is kind of hard because you're wondering a lot of things, and you don't really know, like, 'Do I want to know this? Or this?- Or can I do both so I can figure out this?'
Interviewer: Did it become easier over time to do it?
Will: Yeah. Over time, it definitely gets easier.

Will explained their struggle not as an obstacle but as an endeavor they were pursuing, with the sentence frames encouraging them to engage metacognitively about what they thought about their observations of the graph trends.

In the first iteration of the Share-Out presentations, students were provided with little formal guidance, resulting in a high degree of variance in the use and quality of CER discourse. Most students did not directly offer evidence from their own data for the recommendations they presented to their community partner (CP). However, in the second iteration, the Share-Out preparation engaged the students in developing unified, formal scientific arguments based on evidence they had collected together, reasoning using concepts they had learned together, and claims relevant to the CP's questions and needs. We see here the classroom discourse that emerged during a 4th-grade class during the second iteration's share out preparation lesson.

Badger: wrapping up the session, asked the group to make a claim about whether the data was similar or different between managed and unmanaged plots.
Edward: They are both similar and different. Cause … (looking at the data table) No, no … (he drags the sheet closer to him and examines it) No …
Will: We found out that our unmanaged plot had the lowest shrub diversity. But a different unmanaged plot had the highest shrub diversity. So, we think that the unmanaged plot is very unpredictable.

Focal youth in this class session made clear claims based on their data, scaffolded by the OF facilitator Badger. They then used this data to make meaning of their plots and claims based on evidence in preparation for their presentation to their CP.

Discussion

We found that the Our Forests (OF) design features, Students Engaging in Data Analysis and Sharing Findings with Community Partners, supported student development of ESA and that using DBR to iteratively revise these features allowed for greater student ESA development in the final implementation of the program. Our study provides a rich example of how DBR can be used in CCS program design and CCS education research to continuously improve learning interventions and generate rigorous, theoretically sound evidence of learning outcomes, as the NASEM (2018) committee suggested. Our findings have shown that the iterative design of a school-based CCS program can help support ESA development, highlighting the role these often underrepresented components of the data life cycle play. These findings corroborate those from several other studies examining schools partnering with scientists in the context of citizen science, where conversations (live or asynchronous) with scientists enhanced students understanding of the scientific work of the project (Aridor et al., 2023; Bird et al., 2023). In addition to contributing to the scholarship on science learning, we offer here recommendations for CCS program design for in – and out-of-school settings, specifically around ways to facilitate and scaffold youth making meaning with data and sharing findings with key stakeholders, which we see as intertwined to maximize science learning.

We found that the programmatic embodiments of these design features supported all aspects of ESA, though ESA 1 and ESA 2 more than ESA 3. Examples of this learning included students demonstrating disciplinary knowledge (e.g. density and diversity of their plots) and skills (e.g. data comprehension and presentation) (ESA 1), enacting science identity through expression of increased competence in relevant skills (ESA 2) and generating and sharing novel ideas for how their findings could be used to improve forest health (ESA 3). This learning emerged not just from these design features, but from a broader CCS program centered on a real-world issue, approached through the complete data life cycle. Similarly, Solé et al. (2024) identified four categories through a systematic literature review of citizen science in formal education contexts: students using science, students helping science, students learning science collecting data, and students learning science by acting as scientists. By demonstrating the learning impacts of a program that effectively includes all of these areas, our findings embody and buttress their arguments for the importance of comprehensive programs like OF.

We found that when students had well-scaffolded opportunities in the second iteration to share their investigation findings with their CP at the end of the year, they experienced better opportunities to learn. They produced and presented a high-quality disciplinary text (their Share-Out presentation), developed and defended claims and reasoning based on evidence, and in some cases, engaged in back-and-forth arguments with their CP that positioned them as experts (Mercer & Littleton, 2007). When students are positioned as experts in their community of practice, they learn through becoming developing practice related identity (Lave & Wenger, 1991; Rogoff, 2014).

This was present in our findings, as a higher occurrence of science identity was found in the program's second iteration.

We found that Sharing Findings provided a contextualizing purpose for Data Analysis (Harris et al., 2020; Piatek-Jimenez et al., 2012), which was reinforced in the second iterations Share Out scaffolding. With the added data analysis practice and the addition of independent work in the second iteration, students shared their data in a way that provided more data-driven recommendations (Bird et al., 2023). Thus, while ESA learning was evidenced in each design feature, we see the importance of building connections and skills across these to deepen students' connection to and learning within a school-based CCS project (Solé et al., 2024).

In fact, ours and these previous studies provide evidence that rather than being in competition with each other as is often posited and debated in the CCS literature (Jadallah & Wise, 2023; Kobori et al., 2016; Parrish et al., 2018), the scientific goals and the educational goals in OF are not only intertwined but interdependent to effectively foster students' ESA development. When the science curriculum standards alone were prioritized in activities in the first iteration of the program, many students' development of identity and agency with science were not as rich or complex as during the second iteration, when earlier and more frequent framing and preparations to share their findings with their CP. This speaks to the importance of designing CCS programs for students with both teachers and scientist partners involved from the beginning, which can be done as part of a DBR process as we have done and is also suggested by Bopardikar et al. (2023) and Atias et al. (2023) who offer other structured processes for education researchers to partner with teachers and scientists in the design of CCS.

Finally, it is important to acknowledge that while we found important science learning outcomes as a result of engaging students in the whole data lifecycle, and particularly through sharing their findings with an authentic community partner, there are ways in which the intensive scaffolding for students removes some of the authenticity of doing real science for students. Important critiques of school-focused CCS suggest that when it is largely prescribed, scripted, and focused on rigid protocols, the extent to which students are truly asking and answering their own questions about issues they care about may be minimal and even disempowering (Calabrese Barton, 2012). In fact, many participatory approaches focused on student – and community-driven science make space for students' own epistemologies and funds of knowledge (O'Neill et al., 2023; Tan & Faircloth, 2023) in ways that the program did not. This might contribute to what we see in our findings, as while students' ESA learning was strongly developed in content knowledge and skills, we saw fewer examples of students acting with agency to make change beyond the program in their communities. So, while students working in collaboration with local forest managers to address real community concerns like wildfire risk is certainly getting closer to answering the call for more community involvement in school-focused CCS (Ballard, 2023; Kali et al., 2023), as a field, we should continue to work toward balancing the goals of meeting science curriculum standards while also opening the space and time for students to pursue their own epistemologies to meet community needs, which is possible (Tan & Faircloth, 2023), but certainly not easy.

Conclusions

As a study of what school-based community and citizen science can look like when design goes beyond students collecting data, we found the Our Forests program supported student development of ESA in a variety of ways. We also found that using DBR to iteratively revise these features of the program allowed for greater student ESA development in the final implementation of the program. Specifically, we found that repeated exposures to and individual practice with data analysis skills (e.g. making meaning of data in relation to research goals, interpreting and making graphs) supported students' development of data literacy skills and science identity as they had the chance to practice and get better at working with the data in ways often limited in elementary classrooms (NGSS, 2013). When students were given the opportunity to share their findings with meaningful audiences, we found that increased scaffolding for the preparation of their Share-Out presentations increased students' ability to produce and share data-driven presentations with the community partner, better engage in scientific discussion, and demonstrate a clearer understanding of disciplinary knowledge.

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Ethics statement

This study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of the University of California, Davis (protocol code 1503379–4 and approved on 04/06/2021).

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References

Aridor, K., Dvir, M., Tsybulsky, D., & Ben-Zvi, D. (2023). Living the DReaM: The interrelations between statistical, scientific and nature of science uncertainty articulations through citizen science. *Instructional Science*, *51*(5), 729–762. https://doi.org/10.1007/s11251-023-09626-8

Atias, O., Baram-Tsabari, A., Kali, Y., & Shavit, A. (2023). In pursuit of mutual benefits in school-based citizen science: Who wins what in a win-win situation? *Instructional Science*, *51*(5), 695–728. https://doi.org/10.1007/s11251-022-09608-2

Ballard, H. L. (2023). Community and citizen science in schools: Nested inquiries, productive tensions, and the role of communities. *Instructional Science*, *51*(5), 913–919. https://doi.org/10.1007/s11251-023-09643-7

Ballard, H. L., Dixon, C. G., & Harris, E. M. (2017). Youth-focused citizen science: Examining the role of environmental science learning and agency for conservation. *Biological Conservation*, *208*, 65–75. https://doi.org/10.1016/j.biocon.2016.05.024

Basu, S. J., Calabrese Barton, A., Clairmont, N., & Locke, D. (2009). Developing a framework for critical science agency through case study in a conceptual physics context. *Cultural Studies of Science Education*, *4*(2), 345–371. https://doi.org/10.1007/s11422-008-9135-8

Bell, P. (2004). On the theoretical breadth of design-based research in education. *Educational Psychologist*, *39*(4), 243–253. https://doi.org/10.1207/s15326985ep3904_6

Bell, P., Van Horne, K., & Cheng, B. H. (2017). Designing learning environments for equitable disciplinary identification. *Journal of the Learning Sciences*, *26*(3), 367–375. https://doi.org/10.1080/10508406.2017.1336021

Bird, E. B., Ballard, H. L., & Harte, M. (2023). Data to decision-making: How elementary students use their Community and Citizen Science project to reimagine their school campus. *Instructional Science*, *51*(5), 763–791. https://doi.org/10.1007/s11251-022-09612-6

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen science: A developing tool for expanding science knowledge and scientific literacy. *BioScience*, *59*(11), 977–984. https://doi.org/10.1525/bio.2009.59.11.9

Bopardikar, A., Bernstein, D., & McKenney, S. (2023). Designer considerations and processes in developing school-based citizen-science curricula for environmental education. *Journal of Biological Education*, *57*(3), 592–617. https://doi.org/10.1080/00219266.2021.1933134

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences*, *2*(2), 141–178. https://doi.org/10.1207/s15327809jls0202_2

Calabrese Barton, A. M. (2012). Citizen (s') science. A Response to" The Future of Citizen Science". *Democracy and Education*, *20*(2), 12.

Chambers, R. (1994). Participatory rural appraisal (PRA): Analysis of experience. *World Development*, *22*(9), 1253–1268. https://doi.org/10.1016/0305-750X(94)90003-5

Cooper, C. B., Hawn, C. L., Larson, L. R., Parrish, J. K., Bowser, G., Cavalier, D., Dunn, R. R., Haklay, M., Gupta, K. K., Jelks, N. T. O., & Johnson, V. A. (2021). Inclusion in citizen science: The conundrum of rebranding. *Science*, *372*(6549), 1386–1388. https://doi.org/10.1126/science.abi6487

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. SAGE Publications.

Dibner, K. A., & Pandya, R. (Eds.). (2018). *Learning through citizen science: Enhancing opportunities by design*. National Academies Press.

Doering, A., & Veletsianos, G. (2007). Multi-scaffolding environment: An analysis of scaffolding and its impact on cognitive load and problem-solving ability. *Journal of Educational Computing Research*, *37*(2), 107–129. https://doi.org/10.2190/Q58T-4388-8015-8141

Eitzel, M., Cappadonna, J., Santos-Lang, C., Duerr, R., West, S. E., Virapongse, A., Kyba, C., Bowser, A., Cooper, C., Sforzi, A., & Metcalfe, A. (2017). Citizen science terminology matters: Exploring key terms. *Citizen Science: Theory and Practice*, *2*(1), 1–20. https://doi.org/10.5334/cstp.96

Fortmann, L., & Ballard, H. (2011). Sciences, knowledges, and the practice of forestry. *European Journal of Forest Research*, *130*(3), 467–477. https://doi.org/10.1007/s10342-009-0334-y

Germann, P. J., & Aram, R. J. (1996). Student performances on the science processes of recording data, analyzing data, drawing conclusions, and providing evidence. *Journal of Research in Science Teaching: The Official Journal of The National Association For Research İn Science Teaching*, *33*(7), 773–798.

Gibson, J. P., & Mourad, T. (2018). The growing importance of data literacy in life science education. *American Journal of Botany*, *105*(12), 1953–1956. https://doi.org/10.1002/ajb2.1195

Gould, R., Sunbury, S., & Dussault, M. (2014). In praise of messy data: Lessons from the search for alien worlds. *The Science Teacher*, *81*(8), 31. https://doi.org/10.2505/4/tst14_081_08_31

Harlin, J., Kloetzer, L., Patton, D., & Leonhard, C. (2018). *Turning students into citizen scientists*. UCL Press.

Harris, E. M., Dixon, C. G., Bird, E. B., & Ballard, H. L. (2020). For science and self: Youth interactions with data in community and citizen science. *Journal of the Learning Sciences*, *29*(2), 224–263. https://doi.org/10.1080/10508406.2019.1693379

Israel, M., Wherfel, Q. M., Pearson, J., Shehab, S., & Tapia, T. (2015). Empowering K–12 students with disabilities to learn computational thinking and computer programming. *TEACHING Exceptional Children*, *48*(1), 45–53. https://doi.org/10.1177/0040059915594790

Jadallah, C. C., & Wise, A. L. (2023). Enduring tensions between scientific outputs and science learning in citizen science. *Biological Conservation*, *284*, 110141. https://doi.org/10.1016/j.biocon.2023.110141

Kali, Y., Sagy, O., Matuk, C., & Magnussen, R. (2023). School participation in citizen science (SPICES): Substantiating a field of research and practice. *Instructional Science*, *51*(5), 687–694. https://doi.org/10.1007/s11251-023-09638-4

Kastens, K., Krumhansl, R., & Baker, I. (2015). Thinking big. *The Science Teacher*, *82*(5), 25–31. https://doi.org/10.2505/4/tst15_082_05_25

Kelemen-Finan, J., Scheuch, M., & 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. https://doi.org/10.1080/09500693.2018.1520405

Kjelvik, M. K., & Schultheis, E. H. (2019). Getting messy with authentic data: Exploring the potential of using data from scientific research to support student data literacy. *CBE—Life Sciences Education*, *18*(2), es2.

Kobori, H., Dickinson, J. L., Washitani, I., Sakurai, R., Amano, T., Komatsu, N., & Miller-Rushing, A. J. (2016). Citizen science: A new approach to advance ecology, education, and conservation. *Ecological Research*, *31*(1), 1–19. https://doi.org/10.1007/s11284-015-1314-y

Langen, T. A., Mourad, T., Grant, B. W., Gram, W. K., Abraham, B. J., Fernandez, D. S., Carroll, M., Nuding, A., Balch, J. K., Rodriguez, J., & Hampton, S. E. (2014). Using large public datasets in the undergraduate ecology classroom. *Frontiers in Ecology and the Environment*, *12*(6), 362–363. https://doi.org/10.1890/1540-9295-12.6.362

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge university press.

Magnussen, R., & Hod, Y. (2023). Bridging communities and schools in Urban development: Community and citizen science. *Instructional Science*, *51*(5), 887–911. https://doi.org/10.1007/s11251-023-09641-9

Mercer, N., & Littleton, K. (2007). *Dialogue and the development of children's thinking: A sociocultural approach*. Routledge.

National Academy of Sciences, Engineering and Mathematics. (2018). *Learning through citizen science: Enhancing opportunities by design*. The National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. National Academies Press.

O'Neill, T., Finau-Faumuina, B. M., & Ford, T. U. L. (2023). Toward decolonizing STEM: Centering place and sense of place for community-based problem-solving. *Journal of Research in Science Teaching*, *60*(8), 1755–1785. https://doi.org/10.1002/tea.21858

Parrish, J. K., Burgess, H., Weltzin, J. F., Fortson, L., Wiggins, A., & Simmons, B. (2018). Exposing the science in citizen science: Fitness to purpose and intentional design. *Integrative and Comparative Biology*, *58*(1), 150–160.

Phillips, T. B., Parker, A., Bowser, A., & Haklay, M. (2021). Publicly generated data: The role of citizen science for knowledge production, action, and public engagement. In C. C. Ferreira & C. F. C. Klütsch (Eds.), *Closing the knowledge-implementation gap in conservation science: Interdisciplinary evidence transfer across sectors and spatio-temporal scales* (pp. 83–107). Springer.

Piatek-Jimenez, K., Marcinek, T., Phelps, C. M., & Dias, A. (2012). Helping students become quantitatively literate. *The Mathematics Teacher*, *105*(9), 692–696. https://doi.org/10.5951/mathteacher.105.9.0692

Roche, J., Bell, L., Galvão, C., Golumbic, Y. N., Kloetzer, L., Knoben, N., Laakso, M., Lorke, J., Mannion, G., Massetti, L., Mauchline, A., Pata, K., Ruck, A., Taraba, P., & Winter, S. (2020). Citizen science, education, and learning: Challenges and opportunities. *Frontiers in Sociology*, *5*, 613814. https://doi.org/10.3389/fsoc.2020.613814

Rogoff, B. (2003). *The cultural nature of human development*. Oxford university press.

Rogoff, B. (2014). Learning by observing and pitching in to family and community endeavors: An orientation. *Human Development*, *57*(2-3), 69–81. https://doi.org/10.1159/000356757

Sandoval, W. (2014). Conjecture mapping: An approach to systematic educational design research. *Journal of the Learning Sciences*, *23*(1), 18–36. https://doi.org/10.1080/10508406.2013.778204

Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B. V., Krasny, M. E., & Bonney, R. (2012). Public participation in scientific research: A framework for deliberate design. *Ecology and Society*, *17*(2), 29. https://doi.org/10.5751/ES-04705-170229

Solé, C., Couso, D., & Hernández, M. I. (2024). Citizen science in schools: A systematic literature review. *International Journal of Science Education, Part B*, *14*(3), 1–17.

Tan, E., & Faircloth, B. (2023). One World: Refugee youth incubating epistemologies toward rightful presence with/in community-driven STEM. *Journal of Research in Science Teaching*, *60*(8), 1627–1656. https://doi.org/10.1002/tea.21846

Wolff, A., Gooch, D., Montaner, J. J. C., Rashid, U., & Kortuem, G. (2016). Creating an understanding of data literacy for a data-driven society. *The Journal of Community Informatics*, *12*(3), 9–26.

Wolff, A., Wermelinger, M., & Petre, M. (2019). Exploring design principles for data literacy activities to support children's inquiries from complex data. *International Journal of Human Computer Studies*, *129*, 41–54. https://doi.org/10.1016/j.ijhcs.2019.03.006

Appendix

Appendix 1. Pre/Post Survey Questions

Pre-Survey	Post-survey
I like to learn about nature, like where animals live or how plants grow.	I spend time thinking about our local forests.
I like to spend time exploring our local forests.	I feel ________ when I am in our local forests *(check all that apply)*:
I think our local forest is healthy.	Write 1–2 sentences: Why does our local forest make you feel that way?
Write 1–2 sentences: Why do you think it is or isn't healthy?	I am able to observe our local forest to learn about it.
I am able to observe our local forest to learn about it.	I think our forest is healthy.
I enjoy being in nature with my family and people who care about me.	Write 1–2 sentences: Why do you think it is or isn't healthy?
I feel ________ when I am in our local forests *(check all that apply)*:	I got better at collecting data while doing the Our Forests activities.
Write 1–2 sentences: Why does our forest make you feel that way?	I got better at reading and understanding graphs while doing the Our Forests activities
I am good at documenting or writing about what I see in the forest.	I got better at talking or writing about data while doing the Our Forests activities.
Write 1–2 sentences: What is science to you?	I got better at talking or writing about what I observed in the forest.
I like to learn about science in different ways.	I got better at making close observations.
Science is my favorite subject in school.	I can imagine myself doing science in my job someday.
The people who care for me are interested in science.	I felt like I was doing science when I used science tools to take measurements of our forest, like rulers, magnifying glass, and thermometers.
I am good at talking or writing about data.	I liked working with the data we collected about our forests.
I am good at making close observations.	I felt like I was doing science when I collected data at our forest site.
I feel like I'm doing science when I collect data.	I felt like I was doing science when I analyzed data about our forest site.
I have ideas about scientific questions I want to ask about our local forest.	I felt like I was doing science when I shared data about our forest site with our community partner.
I can imagine myself doing science someday.	I am able to use my science knowledge and skills to help our local forest.
I feel like I'm doing science when I use rulers, magnifying glasses, and thermometers.	I can think of ways I'd like to collect data about our local forest.
I feel like I am doing science when I am graphing and analyzing data.	I have ideas about more scientific questions I want to ask about forest health.
I can imagine myself as a scientist someday.	Sharing data about our forest with our community partner made me want to help the forest.
I am able to use my science knowledge and skills to help our local fores	I've told other people about our local forest based on what I learned this year.
I can think of ways I'd like to collect data about our local forest.	I have ideas about how I could help our local forests.
I have ideas about how I could help our local forests.	Write 1–2 sentences: What would you like to do to help our local forests?
Write 1–2 sentences: What would you like to do or think people should do to help our local forests?	

Appendix 2: Observation Field Notes and Analytical Memo Template

Filename:

Observer name:

Date:

School Name:

Teacher Name:

Grade Level:

Observation # for this class

Data files collected (can paste links): List all data files collected from the event using the correct conventions (i.e. for photos, audio, lesson plans etc.).

A. Pre-observations for continuity purposes: To be completed BEFORE observation #2 onward

[Review previous field observations of this class. (1) List below any key moments, class dynamics or questions to pay attention to during this upcoming observation. (2) What do we already know about focal students and what questions do we have about their ESA?]

OBSERVATION DAY

B. Logistical Information and Settings

- **Primary event type (Bold the choice)**: FIZ Trip/ Classroom visit only
- **Present FOCAL Youth IDs**:
- **Absent FOCAL Youth IDs (if any)**:
- **# Students Present out of total size for ratio**:
- **If outside, environmental conditions**: Good / Fair / Poor

Describe:

[We need a detailed description of the environmental conditions, especially for the Field Investigation days, since the condition will affect children's general participation.]

- **Community Participants'** Names and/or positions or relations to the FYs (including SSI, CP, and Chaperon):
- **School Setting/Classroom Setting/Field Investigation Zone (FIZ) if visit the space the first time:**

Describe**:**

[What's your general impression of this space? What things caught your attention? What did you notice immediately?]

C. WHOLE CLASS or FOCAL GROUP/FOCAL YOUTH OBSERVATION NOTES

Copy and paste the curriculum outline for this specific day and grade here and leave only the Headings.

- **ACTUAL TIME (not video recorder time) + Activity Name (curriculum outline) – Participant Structure (Whole Class/Small Group/Pairs/Individual)**

(use this space to add notes for the activity. If the activity is skipped, write down SKIPPED)
ADDITIONAL REFLECTIONS WITH INSTRUCTORS, TEACHERS, CP (if any)

D. Synopsis

Provide a quick synopsis of what happened, what activities the youth did, and who was there (3–5 bullet points).

- Main Topics Covered:
- Main Activities Students engaged in:
- Tools used:
- Framing provided by the instructor about the goals for the day and purpose of the activities:[paraphrasing from the instructor when they frame the goals for the day and how they debriefed it and who are students doing this for – AND observers' overall interpretation of this.]

E: Reflections and takeaways

- What was surprising from this visit?
- What jumped out at you?
- What prior knowledge and experiences do focal youths bring to the classroom visits or the forest investigations?
- How does this visit make you think about the **research questions** (what features of the program seem to support youth development of ESA?), how does this relate to the theory and other research we're engaging with?
- How does this make you think about other field observations/ interviews you've done or will do – lessons for next time?
- Choice quotes or episodes you don't want to forget (approximately when, timestamp?)