ELECTRONIC JOURNAL FOR RESEARCH
IN SCIENCE & MATHEMATICS EDUCATION
VOL. 29, NO. 4, 81-101

Incorporating Participatory Science in Elementary Schools: Teacher and Student Experiences with Outdoor Learning

Sarah J Carrier
North Carolina State University

Danielle R. Scharen
Horizon Research, Inc.

Meredith L. Hayes
Horizon Research, Inc.

P. Sean Smith
Horizon Research, Inc.

Christine Goforth
North Carolina Museum of Natural Sciences

Laura Craven
Horizon Research, Inc.

Lindsey Sachs
Horizon Research, Inc.

ABSTRACT

Science instruction in elementary school provides a base for student understanding of the natural world, yet policies prioritizing mathematics and reading have marginalized science. In response, some teachers have enhanced their science instruction by introducing students to participatory science (PS) projects. Using data from a larger study that examines the development of educative support materials for two existing PS projects, this embedded mixed methods study focuses on teachers' and students' experiences learning outdoors. We compare teachers' weekly log data, surveys, interviews, observations, and student focus groups to document teachers' applications of PS in their science classrooms and outdoors. Teachers report benefits (e.g., purposeful science learning) and challenges (e.g., time constraints, testing pressure) of implementing outdoor PS projects. Teacher and student data document cognitive and affective benefits of students' participation. Implications support the potential for PS projects that include schoolyard activities to supplement elementary science teaching and learning.

Keywords: participatory science, citizen science, elementary school, outdoor education, schoolyard

Introduction

Science instruction in elementary school provides a base for students understanding of the natural world and prepares students for future learning (Appleton, 2013; Curran & Kellogg, 2016). Despite the benefits of early science learning, accountability policies emphasizing mathematics and reading in elementary classrooms have marginalized science instruction (Banilower et al., 2018; Plumley, 2019). In response, some teachers have chosen to enhance their science instruction by introducing students to participatory science (PS) projects, where students have an opportunity to engage in real-world projects as they collect and make sense of the data (Jones et al., 2012; O'Donnell, 2023). The term *citizen science* has been widely debated in the United States, where the study took place; however, we have chosen to use the term *participatory science* for this manuscript to identify the practice of non-professional scientists collecting and contributing scientific data. Our use of participatory science aligns with the primary organization in the United States that recently changed its name from *Citizen Science Association* to *Association for the Advancement of Participatory Sciences*. *Community science* is another term that is sometimes used. In school-based participatory science, students can learn science content, and another important benefit of student engagement in PS is the potential to engage in learning outdoors (Carrier et al., 2013; Szczytko et al., 2018; Feille, 2021; Shume & Blatt, 2019), connecting students with the natural world outside their classroom doors.

In this study, we present data from a larger research project that examined teachers' and students' experiences with PS projects that incorporate outdoor learning experiences. Our research team prepared educative curriculum support materials that are designed to support teacher and student learning (Arias et al., 2016; Davis et al., 2017) for two existing PS projects: Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS) and Lost Ladybug Project (LLP).

We collected data from two groups of teachers who were asked to teach both participatory science projects. Teachers who had access to support materials for the CoCoRaHS project were identified as the CoCoRaHS treatment group, and teachers who had access to LLP support materials were the LLP treatment group. Both groups served as control groups for the project for which they did not have support materials. The key goals of this larger research study were to document whether and how the support materials contribute to teachers' and students' engagement in the projects. In addition to promoting student data collection and sense-making activities, our support materials included opportunities for teachers to expand teaching and learning beyond the four walls of the classroom to the schoolyard. In the present study, we focus on the outdoor learning experiences of teachers and students in our study, and our research questions ask:

1. How do teachers describe their implementation of PS project outdoor instruction?
2. What are teachers' views of their students' experiences with PS in the outdoors?
3. How do students describe their outdoor experiences?

Literature Review

Science Education in Elementary Schools

The elementary school years are a critical time in children's development that build the foundation for students' future learning, and science instruction offers multiple opportunities to connect students' school experiences and their lives outside of school (Irish & Kang, 2018). As teachers seek to provide their students with authentic science experiences, PS projects can offer students opportunities for engaging with their science instruction (Jones et al., 2012).

Despite the importance of early science instruction, policies in recent decades that align school accountability with reading and mathematics testing have resulted in a marginalization of science instruction time and resources in many elementary schools (Banilower et al., 2018; Plumley, 2019).

When the Next Generation Science Standards (NGSS Lead States, 2013) were released in 2013, the primary goals were to engage students in learning about science content and practices by doing science. While 20 states have adopted the standards, others have attempted to adapt their state's standards to align with the *Framework for K-12 Science Education* (National Research Council [NRC], 2012), and at this writing, one state has done neither (National Science Teaching Association [NSTA], 2023). Despite these efforts, few elementary science curriculum materials are aligned to the NGSS (Explore Reports, n.d.; Lowell et al., 2021), often leaving school districts and teachers scrambling to find instructional resources for science. In fact, elementary teachers most frequently create their own instructional materials (Doan et al., 2022). In the context of teachers seeking support for their science, we explore the potential for teacher and student engagement in science and the outdoors through PS projects.

Participatory Science

Participatory science (PS) has been described as the public's participation in science by contributing to the research of professional scientists through data collection and sharing (Bonney et al., 2016). In addition to engaging the public in science research, another goal of PS has been to increase the quantities of data far beyond what can be collected by professional scientists.

Science education reform efforts encourage a shift from teacher-centered to student-centered classrooms, and PS has the potential to help teachers learn to design instruction that centers on students and includes asking questions, data collection, and making sense of data (Shah & Martinez, 2016). While there is limited research on supporting teachers to include PS data collection in schools, PS offers dual potential for increasing the quantity of PS data while enhancing the science education of young learners.

When school-based PS projects connect with existing education standards (Lucky et al., 2014), they can be woven into school activities rather than added on as separate instruction. Although few PS projects include specific supports for teachers, the blending of PS in formal education can help students to envision themselves as contributors to, and part of, the larger science community (Esch et al., 2020). PS projects have also been found to motivate students (Dunn et al., 2016), and nature-based PS can foster connections of students' lives with the natural world and, importantly, in their own outdoor spaces at school (Schuttler et al., 2019). In this study, we present one effort to support elementary teachers' science instruction by introducing them to PS projects that include ongoing data collection across a school year and offer opportunities for connecting students with authentic data collection and sense-making aligned with their academic standards.

Outdoor Education

Learning in the outdoors has a long history. In the early 1900s, open-air schools and outdoor education were promoted for health and hygiene (Quay & Seaman, 2013). Interestingly, prior to World War II, science education primarily referred to nature studies (Appleton, 2013), and while most instruction today occurs indoors, learning about the natural world while in the outdoors has been found to contribute to students' cognitive and affective development (Carrier et al., 2014; Rios & Brewer, 2013; Szczytko et al., 2018).

Outdoor instruction is not limited to science, and importantly, it connects learning across discipline areas (Tan & So, 2019). Outdoor learning is often experiential, connecting with both the body and the mind, and such full body connections have been found to positively influence learners' cognition and emotions (Thorburn & Marshall, 2014). When active outdoor learning experiences are connected to indoor lessons, learning is strengthened. Such experiential learning is beneficial for all students and has been found to be especially beneficial for students who struggle with learning or behavior in traditional classroom settings (James & Williams, 2017; Szczytko et al., 2018). As teachers plan to move instruction outdoors, situating outdoor instruction in the familiar schoolyard can decrease the novelties of field trips (Ayotte-Beaudet et al., 2019; Feille, 2021; Martin, 2003).

The schoolyard expands learning beyond the classroom to a setting where students can engage in the practices of science (NRC, 2012; NGSS Lead States, 2013) that include ongoing observations and investigations in the natural world (Ayotte-Baudet, 2017; Carrier et al., 2014; Rios & Brewer, 2014). The schoolyard is readily accessible and avoids field trip costs and logistical challenges of traveling to outdoor parks or nature centers. The accessibility of the schoolyard facilitates opportunities for student engagement with science practices such as observations, data collection, and sense making aligned with science content studies (e.g., life cycles, seasonal changes, weather) in a setting familiar to students across the entire school year.

Theoretical Framework

This study of students' and teachers' PS experiences in their schoolyard is framed in situated learning theory that acknowledges learning is positioned in context, and the context influences learning (Giamellaro, 2017; Sadler, 2009). When students' experiences take place in outdoor environments, their science learning is situated in the context of study (Giamellaro, 2017) and can include examinations of life, earth, and physical science content. Importantly, moving science instruction from the classroom to the schoolyard offers opportunities for students to connect learning with local phenomena (Lloyd et al., 2018).

In addition, sociocultural learning (Vygotsky, 1978) frames teacher and student learning together in the outdoors, which informed Rogoff's (1990) notion of cognitive development with reciprocal contributions of teachers and students when sharing the dual familiarity of the schoolyard. As suggested by Vygotsky's (1978) sociocultural learning theory, knowledge is constructed in one's community, which includes the local context and social interactions to learn science in their schoolyard with their classmates. Importantly, findings from these data and data from the larger study have informed an emerging theory of school-based participatory science (Smith et al., 2025).

Methods

Context

We begin by presenting the context of the larger study for which we selected two PS projects because of their content area alignment with the state's science standards. One PS project, the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS) aligned with the state's fifth-grade weather standards. The second project, Lost Ladybug Project (LLP) aligned with the state's fifth-grade ecosystems standards. CoCoRaHS was launched in 1998 and currently has over 26,000 active observers in the United States and beyond. Observers collect precipitation data to share with the CoCoRaHS community and help scientists learn more about precipitation patterns (CoCoRaHS, n.d). Examinations of the CoCoRaHS project describe its potential for engaging participants in science (e.g., Jones, 2022; Lackstrom et al., 2022; Mahmoudi et al., 2022), but few promote connections with schools (Sheppard et al., 2022). LLP began in 2000 and was designed to help entomologists document the types and numbers of ladybug species in the US with a goal to conserve declining ladybug populations (The Lost Ladybug Project, n.d.). As with CoCoRaHS, research on LLP primarily identifies participants in the public rather than specific connections with schools (Gardiner et al., 2012; Losey et al., 2012; Lynch et al., 2018; Marchante et al., 2024). The context of the present embedded mixed methods study focuses on teacher and student experiences with the PS projects with a special focus on outdoor teaching and learning.

Participants

Twenty-three fifth-grade teachers and approximately 450 students across one state in the southeastern United States agreed to participate in the first year of this study. Each teacher was asked to incorporate both PS projects - CoCoRaHS and LLP - with their fifth-grade classrooms, but they received support materials for only one of the projects. By providing support materials for only one of the two PS projects to treatment group teachers, our research team sought to learn if and how having support materials contributed to teachers' incorporation of PS with their students. The educative support materials (Arias et al., 2016; Davis et al., 2017) for both projects were designed for this study, created by the research team, and located on a website. Both projects' materials include monthly lessons (August–June), content resources for science, mathematics, and literacy for teachers, and a media guide that includes content-specific readings, videos, books, and interactive guides that related to the project. Both PS projects' support materials include the same teacher recommendations for outdoor instruction such as establishing expectations prior to taking the class outdoors for learning, using multiple senses to make observations outside, collecting and recording data, and exploring students' wonder and curiosity.

The teacher participants were introduced to the two PS projects by attending an in-person professional development for one day over the summer. The professional development included opportunities to begin to consider the inclusion of PS in their classrooms in the upcoming school year. We asked the teachers to implement both projects, though they had support materials for only one project, their treatment group, and teachers served as control group teachers for the PS project for which they did not have educative support materials.

Teachers also attended virtual sessions once a month across the school year for one hour with the research team and other teachers in their treatment group to preview the upcoming month's support materials and discuss their projects. These meetings were held on the same days for each treatment group on the first Wednesday or Thursday of the month after school hours (4:30pm). Meetings for both projects followed the same structure, and while they only discussed the instructional materials of projects for which teachers had support, the meeting schedule included time for teachers to talk about both projects.

Data Collection

This mixed methods study includes both qualitative and quantitative data from teachers and their students (See Table 1). Quantitative data were collected from 23 teacher participants who completed baseline and end-of-year surveys that included questions about how conducive their schoolyard was for outdoor learning related to the PS projects and the amount of time they spent teaching science outdoors in previous years. We also asked teachers about their prior experiences or understanding of PS and their reasons for joining the project. Once the school year began, we asked the 23 teachers to submit weekly instructional logs that asked them to document their activities and classroom decisions related to the PS project, including their estimates of the frequency and approximate percentage of students who spent time outdoors.

Table 1

Data Sources

	Data Sources	Participants			
		All Teacher Participants	Only Case Study Teachers	All Students	Only Students in Case Study Classrooms
Quantitative	Baseline Survey	X		X	
	Instructional Logs	X		X	
	End-of-year Survey	X		X	
	Content Area Pre-test Ecosystems/ Weather	X		X	
	Content Area Post-test Ecosystems/ Weather	X		X	
Qualitative	Beginning and End-of-Year Interviews		X		
	Six Classroom Observations		X		X
	Post-observation interviews		X		
	Three Focus Groups (Beginning, Middle, and End of Year)				X

To provide a closer look at project implementation, we collected qualitative data with 11 of the 23 teachers as case study participants. From the teachers who expressed interest in participating as case study teachers, we purposefully selected teachers to represent the range of the state's geographic regions, school characteristics (e.g., rural, urban, size), and student populations. While the demographics of teachers in this study were typical of elementary school teachers (i.e., white, female) (Plumley, 2019), we use gender neutral pseudonyms for case study teachers in this paper (Table 2).

Table 2

Participant Design

Group	Treatment Project (Received Support Materials)	Control Project (Did Not Receive Support Materials)	Case Study Teachers
Group A Teachers	LLP	CoCoRaHS	Astor, Jordan, Lian, Taylor
Group B Teachers	CoCoRaHS	LLP	Dana, Morgan, Kody, Perry, Kai, Asa

Note. We use gender neutral pseudonyms for case study teachers in this paper

Project researchers *observed* each case study teacher's "target" science class (for instances when a teacher taught science to more than one class) at least six times over the school year and documented the observations using an observation guide that was developed by the research team. The observation guide helped researchers record the type of activity (e.g., data collection, class discussion, group work), setting (indoor or outdoor), grouping structure (e.g., whole class, small group), proportion of students engaged in the activity (e.g., 50-75%, 75-100%), and interdisciplinary connections (e.g., mathematics, language arts). Researchers recorded field notes on the observation guide using time stamps to document the length of each of the activities observed. Researchers *interviewed* the case study teachers seven times starting with a baseline interview prior to the first observation, then conducted post-observation interviews following each of the six observations. The interviews asked teachers about their PS lesson planning, implementation, reflections on their students' experiences with PS in the classroom and schoolyard, and their interactions with the support materials. In each case study teacher's class, the project researchers also conducted three *focus group* interviews with students near the beginning, middle, and end of the school year. The teachers selected four to six students with parent consent and student assent, and each of the three focus groups consisted of different student participants.

Data Analysis

Quantitative data included teacher baseline and end-of-year *surveys* that examined teachers' prior experiences with PS and outdoor instruction. Weekly *instructional log data* were analyzed for patterns using the PS projects both in the classroom and the schoolyard. Log data documented teachers' accounts of the frequency and time of their engagement with the PS projects, use of support materials, and teachers' considerations that informed their planning and instruction.

Qualitative *classroom observation* field notes combined with *teacher interviews* were recorded and transcribed. We used inductive coding to identify initial codes and organized them by themes (Riger & Sigurvinsdottir, 2016). Following discussions on initial themes and code meanings (Chandra et al., 2019), two researchers independently coded the same interviews, discussed differences, and through negotiated agreement (Belotto, 2018) reconciled the remaining differences. The researchers identified common interpretations of themes that captured teachers' and students' experiences with outdoor learning. Themes include teacher views of outdoor instruction, their views of students' outdoor experiences, and student impressions of outdoor instruction. *Student focus group* data document students' cognitive and/or affective reactions to the outdoors, classroom connections, connections to their lives, and students' feelings about learning outdoors (Table 3).

Table 3

Themes, Descriptions, and Sample Quotes

Code	Description	Sample Quotes
	Theme: Teacher Views about Outdoor Instruction	
Authentic learning experiences in the outdoors	Teachers' descriptions of the authenticity of teaching outdoors	*Now I am taking them out for more of a purpose. (Astor)*
Schools' focus on test preparation	Teachers' views on standardized testing pressures	*It gave me permission, quite frankly because I was part of this study…I got permission from up high to walk away from teaching to the test. So that's a really good thing because it felt more authentic. (Morgan)*
Situating learning outdoors	Teachers' views on moving instruction outdoors	*Outdoor learning reinforces that learning can be anywhere. (Kody)*
Benefits of outdoor instruction	Teachers' views on positive aspects of outdoor instruction	*I think they always love the outdoors. I got outdoors way more this year than I did before, and I really think that that was a good idea and I will be doing that again next year. (Kai)*
Challenges of outdoor instruction	Teachers' views on obstacles to outdoor instruction	*I had great intentions but one of my barriers was I don't really have a safe way for the students to go out and check the rain gauge without me. (Lian)*
	Theme: Teacher Views about Student Experiences in the Outdoors	
Student enthusiasm for the outdoors.	Teachers' views on students' excitement about outdoor lessons	*They had the freedom to move around in a space that they don't normally get to run around and move in with the purpose. And I think anytime you can get outside you feel better. (Astor)*
Students' limited outdoor experiences	Teachers' views on their students spending little time outdoors	*The most rewarding aspect of Lost Ladybug was) getting them outside because they need to learn that you don't have to be behind a computer to learn. (Kody)*
Students' engagement in learning outdoors	Students' engagement in learning when outdoors	*Going outside is always very engaging, so they really enjoyed that. That was fun. And I haven't taken the class outside in a while, so it was helping me remember, oh, kids really, really do enjoy going outside.' As long as we have a specific purpose for why we're outside. (Perry)*
	Theme: Student Views about the Outdoors	

Cognitive reactions to the outdoors	Students sharing cognitive connections outdoors.	*I feel more thoughtful about things in the outdoors*
Affective reactions to the outdoors	Students' descriptions of feelings when outdoors.	*Outside is more calm than in the classroom. Classrooms are wild*
Classroom connections	Students connecting indoor lessons with outdoor learning.	*[PS Connects to] what we do in social studies, we do latitude and longitude, prime meridian, equator.*
Connections to students' lives	Students' reflections on outdoor learning with their own lives.	*It's changed me a lot, because now every time I go outside, I always look up on the clouds and now it's a habit.*
Learning in the outdoors	Students' comments about learning when outdoors.	*I've never seen clouds that look like that before, and before this I never even noticed anything. So, this has helped me learn a lot.*

Limitations

We acknowledge that the teachers chose to participate in this study, introducing self-selection bias. We further recognize that elementary school outdoor areas vary widely and can limit student access for data collection with some PS projects, thus limiting the generalizability of these findings. While there were urban schools in this study, we recognize that one factor that influenced teachers' decisions to participate in this study was the potential of their schoolyard for outdoor data collection. This includes presence of vegetation and attention to safety concerns.

Findings

Quantitative – Surveys and Instructional Logs

Survey data

At the start of the study, teachers completed a baseline survey that included questions about their feelings of preparation to use their school grounds to teach science and how frequently they took their students outside for science instruction in the previous year. Teachers answered the same questions on the end-of-year survey. On the baseline survey, about 70 percent of the teachers said they did not have science instructional materials designated by their school/district. Sample data in Table 4 reveal slight variations in survey data with no significant changes in teachers' feelings of preparedness for outdoor instruction after one academic year.

Table 4

Sample Survey Data

	How well prepared do you feel to use your school grounds to teach science?			
	Not adequately prepared	Somewhat prepared	Fairly well prepared	Very well prepared
Baseline Survey (N=23)	3	4	10	6
End-of-year Survey (N=22)	1	5	11	5

	How often do you take your students outside for science instruction?				
	Never	Rarely	Sometimes (once a month)	Often	All or almost all
Baseline Survey (N=23)	1	6	13	3	0
End-of-year Survey (N=22)	0	7	8	6	1

Instructional Log Data

Weekly instructional log data revealed variations in time spent on each PS project and time outdoors. Instructional log data for *all* participants documented teachers spending little time on projects for which they did not have support materials. For CoCoRaHS treatment teachers who had CoCoRaHS support materials, weekly log data show that their students spent an average of about 26 minutes each week on activities related to CoCoRaHS (e.g., reading the rain gauge; submitting data), and 18 minutes each week for activities related to LLP (e.g., searching for ladybugs; submitting data). For teachers who had LLP support materials, weekly log data show that their students spent an average of about 38 minutes each week on activities related to LLP and 13 minutes each week on activities related to CoCoRaHS.

Teachers were asked, “How much time did a typical student in this class spend outdoors as a part of [LLP or CoCoRaHS] this week?” Log data indicated that students went outdoors more frequently for CoCoRaHS (5,565 total minutes) than LLP (3,486 total minutes), collecting precipitation data most days with one to four students reading the rain gauge. Interestingly, while the teachers’ log data indicated that students went outdoors less frequently for LLP compared to CoCoRaHS, when they went outside, more students (the entire class of approximately 20 students) went outdoors to search for ladybugs, and they also spent more time outdoors when compared to CoCoRaHS. These log data were reinforced by the observation and interview data collected with the case study teachers, helping us learn more about teachers’ views of their own and their students’ experiences learning outdoors.

Qualitative - Interviews, Observations, and Student Focus Groups

In the baseline interview, we asked about their school's science curriculum, their familiarity about PS, and enactment of the PS projects. Teachers reported that, while their state posted elementary science standards, most districts did not provide curriculum or instructional materials for science. When asked about curriculum and instructional resources, Morgan reported using a "Scholastic magazine, and various online resources, but it's up to me how to design it and use those resources." A baseline interview question asked case study teachers about their familiarity with PS, and Perry said "I was familiar with the idea of it, but not fully firm on what it meant. I just thought it was doing kinds of outdoorsy stuff with your kids that benefited the outdoors, like ecosystems." As with teachers' log data, field notes from researchers' observations of the case study teachers' lessons and teacher interviews found teachers spent little time on projects for which they did not have support materials. In an end-of-year interview, when asked about LLP, Perry, who had support materials for CoCoRaHS said, "I haven't worked with that (LLP) as much or hardly at all," and explained that without support materials, they were unsure what to do.

Observations

Here we describe sample observation data from two case study teachers' enactment of their PS project's introductory activity. CoCoRaHS: Morgan, who had materials for CoCoRaHS, used an introductory activity from the materials and took the entire class outside on a "weather walk" to orient students to using their senses and rain gauge measurements to collect weather data and introduced students to the location of the rain gauge. Students' sensory observations included looking at clouds and identifying cloud types, discussing how the air felt on their skin, touching dew on the grass and speculating how the dew got there. After the whole-class introduction of the CoCoRaHS project in the outdoors, observation data from the remainder of the school year documented that Morgan sent only one student or a small group (2-4 students) outdoors to collect rain gauge data at the start of the school day. Many of the monthly CoCoRaHS activities were designed to give students experiences organizing and making sense of precipitation data; the observation data documented that, in Morgan's class, these monthly frequently occurred indoors.

An example of Taylor's enactment of LLP documented their adaptation of an introductory activity from the support materials designed to orient students to the schoolyard as an outdoor classroom and connect with state science standards on ecosystems. In the activity, students were asked to map their schoolyard and identify its features and types of vegetation. The goal of this initial activity was for students to the use their maps throughout the school year to document the locations where they found ladybugs. Rather than asking students to draw maps, Taylor chose to prepare a map template of the schoolyard in advance prior to taking the students outside and asked students to label features on their map and discussed using map keys. Although the purpose of this initial activity was designed to provide students with a map to plot the location of the ladybug sightings across the school year, its use was not documented in observations of Taylor's subsequent monthly activities. Next, we present the case study teachers' reflections on the benefits and challenges of situating instruction in the outdoors, as well as the impact outdoor learning had on their students.

Interviews

Benefits. In interviews, seven of the 11 case study teachers described how the PS projects created more purposeful opportunities for science and outdoor learning throughout the school year. Astor said, "I [used to] take them outside just to do work…but now I'm taking them out for more of a purpose…there's actually a reason." Perry's reflection on PS and purpose was, "Kids really, really do enjoy going outside, as long as we have a specific purpose for why we're outside."

Jordan contrasted the activities from the project's support materials with standards-focused school norms and described its impact on their teaching. They explained:

> This was so much more than just a science lesson or a math lesson. It was so much a part of our class. It was activities that we did together that we enjoyed…It has definitely changed my teaching in that [with PS activity] I wasn't standards-focused, I was purpose-focused.

Other teachers contrasted outdoor instruction with their school's culture focused on accountability and testing. Kyle explained, "I like to be outdoors…I think the kids learned a ton of things that you can't get from a test. I think that we're so tied to doing a test…It's just unfortunate." One case study teacher shared their school's repetitive focus on testing and reviewing, noting that outdoor learning broke up this pattern:

> I think it's something that I get more excited about. At the end of the day, this test is what drives, but it is nice to have that little break once a month to do something different that's not geared toward the test but still on topic. It's hard to justify that sometimes to a principal about doing something that's not on the test. They want us to just teach, teach, teach, review, review, review the whole time.

For some, viewing the outdoor areas of the schoolyard as a setting for learning prompted a shift in both teachers' and students' thinking. Kody reflected that "[PS] reinforces that learning can be anywhere. Outside doesn't have to be recess," and Morgan explained their students' learning "that outdoors can be a learning experience, not just for playtime." Taylor expressed their own intentions to grow:

> I definitely want to try to get them outdoors more…I'm one of those [teachers] - the desks are lined up…it was kind of neat to see how I could teach them outdoors. You know, they don't just have to be sitting behind a desk and listening to me, watching me on the Smart Board, so for sure getting them outside more.

Challenges. During post-observation interviews, case study teachers were asked about challenges they faced with outdoor instruction. Lack of time emerged as a prominent theme; six of the 11 teachers cited the amount of time it took out of the instructional day to go outside. Referring to a limited block of time for science instruction, Dana said:

> We definitely did not go outside as much as I would've liked. So, when it comes to my challenges, time is gonna be a big part of that and just having that time…one of those challenges that I'm gonna try to figure out this summer.

Kody similarly expressed time as the greatest challenge to including outdoor PS saying, "The biggest thing is getting outside and checking that rain gauge and mostly it's because of time constraints."

Other teachers expressed aspirations for planning more outdoor learning opportunities in following years. Lian hoped that their move to a different school would support these goals, "I had great intentions, but one of my barriers was I don't really have a safe way for the students to go out and check the rain gauge without me. But next year they'll be able [to]." For many teachers, the learning curve for adapting new initiatives takes time (Pak et al., 2020), as Morgan described "I didn't do hardly anything with it till the very end because my ecosystem unit is at the end." Promisingly, even the teachers like Jordan, who did not fully implement the PS projects outside in the first year, expressed future intentions, "I'm really excited for next year and the fact that I'm going to start out the year ready to roll with it, more so than I did last year.

Students' Outdoor Experiences

In interviews, many case study teachers described how their students have limited opportunities to experience the outdoors outside of school. Perry shared:

> Some kids don't get outside at all… [One student] didn't really think about being outside and connecting with nature and prefers to stay inside and play a lot of video games. I must remember that not all kids go home and play outside, so it's an important experience for them.

Teachers shared how involvement in the projects provided students with new and meaningful ways to engage with the outdoors. Taylor explained, "[Students] are able to look up from the screens…they definitely have a better appreciation for the outdoors." At the end of the year, Astor shared the lasting impact that the LLP had on their students:

> What they learned is to be observers and aware of their natural surroundings and not just for ladybugs, for everything, because they had so many questions. They'd find another insect, or they'd find a certain flower and they were curious, and they were constantly asking questions. And I think this project has just made them more aware of the natural world around them and it's made them thoughtful. You don't just see a ladybug and or an ant and step on it. You know that everything has a purpose, and I hope that's what they'll take with them.

Other teachers described the ways students' outdoor learning experiences through these PS projects extended beyond searching for ladybugs or measuring precipitation. Lian shared how a student connected the project with her interests of both science and history:

> I had one young lady that brought in a field guide, and she's taking it outside and identifying all the plants and then telling me what the plants were used for in the Civil War. She said, "Did you know this one was used to dye cloth during the Civil War?" So, I saw them taking what we started with our ladybugs and then taking that into their own interests.

Teachers described students' connections of outdoor science with other subjects and to their lives were clear evidence of student enjoyment.

Student Engagement

In addition to sharing students' enjoyment, teachers also described students' enthusiasm for outdoor learning. In their interviews, many case study teachers shared that students were happy when they were outside, had a purpose outdoors beyond playtime, and felt better outdoors. Astor said, "They had the freedom to move around in a space that they don't normally get to run around and move with a purpose. And I think anytime you can get outside you feel better."

In end-of-year interviews, many case study teachers identified getting students outdoors to learn as the most rewarding part of the yearlong project. Jordan described high levels of student engagement in outdoor learning, "All of the students participated. I had 100% participation, 100% feedback. I don't know any other way in school that you get that return on the investment". In addition to their enthusiasm for outdoor instruction, students connected with science: "They like to be outdoors; they spent more time outside this year than ever before - science is their favorite." Astor talked about how impactful it was for students to be part of a community of outdoor scientists:

> I think [the projects] made [science] more real. I think they really believe, and they should believe, they were helping these scientists in the world because I kept telling them, "There's not enough scientists in the world to do all this research, and so we have to help them so they can figure out problems." And I think they felt very much a part of that community of scientists.

Jordan reflected, "It's like they had that purpose for being out there. And it wasn't intimidating to them to be in nature." Some students carried their excitement beyond the classroom and shared their joy for the PS projects at home. Astor described:

> [It was rewarding to] watch my children really grow differently this year than they had in the past. They always grow, but just to see the joy and the excitement when we found our first ladybug, it was just exciting to see them in it. And watching their families get into it and their little brothers and their sisters and all the pictures that were sent from all different places that they were thinking about this, beyond the five days that they go to school. That's impactful.

Student Focus Groups

To gather student perspectives on the projects and time outdoors, we conducted focus groups with different students from each class at the beginning, middle, and end of the school year. Focus groups explored students' impressions of learning in the outdoors, cognitive growth, and connections to their lives. Student quotes include their treatment group project in quotations, CoCoRaHS (CCR) or Lost Ladybug project (LLP).

Learning Outdoors

Many students expressed their appreciation for outdoor experiences. There were several student comments that compared learning outdoors to the classroom: "Being in nature...actually see what you're learning in the classroom (LLP)";" and "Outside is calmer than in the classroom. Classrooms are wild (CCR)." One student said, "It's great for kids to feel like they're more adult. We get to be outside and use our minds rather than sitting inside. Unlike what a normal teacher will do with three days of ladybugs on the screen (LLP)." Other descriptions contrasting outdoor learning experiences with classroom learning included, "I like the outside more. It just seems refreshing to be somewhere that's not class (LLP)"," and, powerfully, "I love going outside. Being free instead of being in jail (CCR)."

Cognitive Benefits

Some students described the cognitive benefits of learning outdoors such as "I feel more thoughtful about things in the outdoors" and that it's "easier to concentrate outside (CCR)." Another student explained, "I'm better at doing precipitation [now]. I just didn't understand that, so you feel like you're understanding the patterns, or even what it means (CCR)." Other students identified how being active contributed to their learning. One student said, "Learning doesn't have to be boring. We can learn more about nature, active learning. It is exquisite (LLP)." Another explained, 'I don't really like bugs a lot, but I like this project because I like doing, and everyone is involved, and I like to DO projects (CCR)." Student comments also included descriptions of student autonomy, "We're going and doing it on our own and we're able to look at these things and research these things on our own, like we're not sitting there watching what somebody else is doing (CCR)."

Students connected their activities to learning the project content and considered the larger impact of the PS projects. Students described how they compared their precipitation data to the data of CoCoRaHS stations across the state, noting, "We can pair the counties to see why they would have more or less rain than us (CCR)," and "I've learned that even though you're not far away from other counties, there is still a big difference in the precipitation they get (CCR)."

Students also considered the ways the PS projects connected to their learning in other content areas. One student referred to the opportunities their class had to graph the precipitation data they collected as part of the CoCoRaHS project, saying, "The graphing was my favorite, because it teaches us to do something. It's math, but like you're not learning it, you're doing something fun (CCR)." Others similarly shared, "I didn't know anything about decimals, and then I figured it out (CCR)" and "Graphing teaches math with fun (CCR)."

Connections to Students' Lives and Learning Outdoors

In each of the three focus groups, researchers asked students about their favorite and least favorite parts about being outdoors. Focus group conversations elicited clear examples of students connecting the projects to their lives and how they interact with the natural world. In their words: "I am more observant; I pay more attention [since participating in PS project] (LLP);" "It's changed me a lot, because now every time I go outside, I always look up at the clouds and now it's a habit (CCR);" and, "It was really cool to learn more about the rain because we don't normally think about it (CCR)." Other students talked about sharing outdoor experiences with their peers. One said "Discovering new insects is great. You get to work together to find out what it is (LLP)." Another student appreciated both the active and social aspects of learning outdoors, "We get to move and talk with each other when we're outside (CCR)."

The focus group data also documented students' least favorite parts of outdoor learning and these focused on inclement weather, bugs, or students' own fears. Sample student comments about their least favorite parts are, "I don't like the ladybug project. Ladybugs are scary (LLP)," and "I don't like my shoes getting dirty whenever we have to walk in the grass to the rain gauge (CCR)," and "sometimes way too hot or too cold (CCR)." As we continue to analyze teachers' interactions with the educative materials for PS, we consider additional ways to support teachers' efforts to reach all students.

Discussion

Extending science learning to the familiar and accessible schoolyard has been found to enhance both student learning and enthusiasm (Aflalo et al., 2020). Aligned with decades of research showing that outdoor learning is beneficial to students' cognitive achievement (e.g., Disinger, 1987), students in this study described both cognitive and affective benefits of situating instruction in the outdoors. Importantly, both teachers and students shared their appreciation for active learning experiences outdoors. Active learning (Mizokami, 2018; Vanhorn et al., 2019) has been defined with language such as "engagement" and "authentic" learning and contrasted with passive listening to a teacher's instruction. Here we argue that PS projects have the potential to support consistent and active learning outside the classroom.

There is a dearth of research on PS projects in elementary schools. One article written for elementary teachers provides a strong introduction of PS and LLP, including examples of PS projects and LLP activities (Harris & Ballard, 2018). Our study extends this research to suggest that developing educative curriculum materials for PS projects can support both teacher and student learning (Arias et al., 2016; Davis et al., 2017). Importantly, incorporating PS projects in formal education offers opportunities to extend learning beyond the classroom to the schoolyard.

In our study, teachers described how these two PS projects that included schoolyard experiences positively impacted students' enthusiasm for science and offered direct connections of science to students' lives (Ayotte-Beaudet et al., 2023; Berg et al., 2021). For example, students described comparing precipitation data from their own rain gauge with precipitation data collected in other geographic locations in their state, demonstrating their excitement for feeling connected to other communities through the CoCoRaHS PS project. These data also reveal examples of students connecting their PS experiences to other subject areas beyond science, including mathematics and social studies (Tan & So, 2019).

In focus group interviews, students shared their enjoyment of learning outdoors and their connections with nature (Ayotte-Baudet, 2017; Carrier et al., 2014; Rios & Brewer, 2014). Participatory science projects that include ongoing data collection in the outdoors can help students recognize their contributions to the work of scientists. "Students can then appreciate what their observations mean and how they might fit with those of others into the missions of broader science initiatives" (Esch et al., 2020, p. 5). In our study, data suggest that, as students learn that data collection in science is not limited to one teaching unit or time frame, they begin to learn more about the work of professional scientists. Such student participation and sharing data collection and sense-making opportunities in the classroom and outdoors with their classmates have been found to deepen collective learning (Krist & Shim, 2024).

Importantly, the PS projects and outdoor instruction in this study seemed to ignite both teacher and student interest (Dillon et al., 2016; Oberle et al., 2021; Rios et al., 2014).
Teachers in this study acknowledged the well-documented challenges of time, preparation for taking students outdoors, and the pressure to prepare their students for standardized testing which mirror challenges found in elementary classroom science education more broadly (Banilower et al., 2018; Plumley, 2019). However, the teachers' perceived benefits of engaging their students in PS projects appeared to motivate them to navigate past these obstacles, and many teachers in this study expressed intentions to engage more frequently or more deeply with the projects and outdoor instruction in the future. Findings from our study also suggest that providing teachers with support materials specific to a PS project can help teachers connect classroom and schoolyard instruction as they contribute data to the PS project.

Implications

Findings from this study suggest that including PS projects in elementary school classrooms can encourage regular outdoor science learning experiences that enhance elementary science instruction and increase students' enthusiasm for learning. Elementary school science programs can benefit from PS projects that include supports designed to meet teacher needs, creating a culture of learning outdoors frequently and with purpose (Barfod & Bentsen, 2018). We suggest that, in partnership with educators (Carrier et al., 2024), PS project leaders can design educative support materials (Arias et al., 2018; Davis et al., 2014) to enhance efforts to expand their PS projects to formal education settings. Such authentic data collection and sensemaking in the schoolyard can provide young learners with science experiences with their peers, as they collect and share data, participating in the enterprise of science. Data from the present study were collected in the first year of a larger study, and because many teachers in this first year described intentions to "do more" in the following school year, this project's continuing research, and future research on PS in formal education can extend our understanding of this study's data over time.

Acknowledgements

NSF Acknowledgement–This material is based upon work supported by the National Science Foundation under Grant No. 2009212. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

The authors received no financial support for the research, authorship, and/or publication of this manuscript

Sarah J. Carrier (sjcarrie@ncsu.edu) taught elementary school and is a Professor of Science Education at North Carolina State University. Her research has included studies of literacy and science, science teacher identity, awe in science, and has focused on issues of climate change and environmental education. Her true heart is supporting elementary teachers situating instruction in the outdoors.

Danielle R. Scharen (d.scharen@horizon-research.com) is a Lead Researcher at Horizon Research, Inc. where she focuses on K-12 science education research. Prior to joining HRI in 2023, Danielle taught undergraduate science education at North Carolina State University and was an elementary school teacher in Wake County Public Schools.

Meredith L. Hayes (Meredith.hayes15@gmail.com) is a research Associate at Horizon Research, Inc., has worked on several projects funded by the U.S. National Science Foundation and the NASA Science Mission Directorate, both as a researcher and external evaluator. In addition, she has taught upper elementary grades and served as the school mathematics/science specialist, working withK-5 students and teachers. Her current work focuses on investigating how teachers implement participatory science projects.

P. Sean Smith (ssmith62@horizon-research.com) is a Senior Executive at Horizon Research, Inc. (HRI), received a Bachelor's Degree in Chemistry, a Master's Degree in Science Teaching, and a Ph.D. in Curriculum and Instruction. He is currently Principal Investigator for the NSF-funded Supporting Elementary Teacher Learning for Effective School-Based Citizen Science (TL4CS). Dr. Smith also leads the evaluations of several projects funded by the U.S. National Science Foundation.

Christine Goforth is the head of citizen science at the North Carolina Museum of Natural Sciences, a role that engages members of the public with scientific research they can participate in as non-experts. Chris holds a BA in Biology from Colorado College and a MS in Entomology from the University of Arizona. Her research areas focus on aquatic insect ethology and physiology as well as using insects to determine water quality in a variety of settings.

Laura Craven (l.craven@horizon-research.com) is a Research Associate at Horizon Research, Inc. where she develops surveys and conducts data analyses for a variety of STEM education projects.

Lindsey Sachs (l.sachs@horizon-research.com) is a research Associate at Horizon Research, Inc. (HRI). She received her Bachelor of Arts degree in Elementary Education from the University of North Carolina at Chapel Hill and a Master of Education degree from North Carolina State University. Prior to joining HRI in 2020, she worked for the Wake County Public Schools.

References

Aflalo, E., Montin, R., & Raviv, A. (2020). Learning outdoors or with a computer: the contribution of the learning setting to learning and to environmental perceptions. *Research in Science & Technological Education*, *38*(2), 208-226. https://doi.org/10.1080/02635143.2019.1603141

Appleton, K. (2013). Science pedagogical content knowledge and elementary school teachers. In *Elementary science teacher education* (pp. 31-54). Routledge.

Arias, A. M., Bismack, A. S., Davis, E. A., & Palinscar, A. S. (2016). Interacting with a suite of educative features: Elementary science teachers' use of educative curriculum materials. *Journal of Research in Science Teaching*, *53*(3), 422–449. https://doi.org/10.1002/tea.21250

Ayotte-Beaudet, J. P., Chastenay, P., Beaudry, M. C., L'Heureux, K., Giamellaro, M., Smith, J., ... & Paquette, A. (2023). Exploring the impacts of contextualised outdoor science education on learning: the case of primary school students learning about ecosystem relationships. *Journal of Biological Education, 57*(2), 277-294. https://doi.org/10.1080/00219266.2021.1909634

Ayotte-Beaudet, J. P., Potvin, P., & Riopel, M. (2019). Factors related to middle-school students' situational interest in science in outdoor lessons in their schools' immediate surroundings. *International Journal of Environmental and Science Education*, *14*(1), 13-32. https://doi.org/10.29333/ijese/7815

Ayotte-Beaudet, J. P., Potvin, P., Lapierre, H. G., & Glackin, M. (2017). Teaching and learning science outdoors in schools' immediate surroundings at K-12 levels: A meta-synthesis. *EURASIA Journal of Mathematics, Science and Technology Education*, *13*(8), 5343-5363. https://doi.org/10.12973/eurasia.2017.00833a

Banilower, E. R., Smith, P. S., Malzahn, K. A., Plumley, C. L., Gordon, E. M., & Hayes, M. L. (2018). *Report of the 2018 NSSME+*. Horizon Research, Inc.

Barfod, K., & Bentsen, P. (2018). Don't ask how outdoor education can be integrated into the school curriculum; ask how the school curriculum can be taught outside the classroom. *Curriculum Perspectives*, *38*, 151-156. https://doi.org/10.1007/s41297-018-0055-9

Belotto, M. J. (2018). Data analysis methods for qualitative research: Managing the challenges of coding, interrater reliability, and thematic analysis. *The Qualitative Report*, *23*(11), 2622-2633. https://doi.org/10.46743/2160-3715/2018.3492

Berg, S., Bradford, B., Barrett, J., Robinson, D. B., Camara, F., & Perry, T. (2021). Meaning-making of student experiences during outdoor exploration time. *Journal of Adventure Education and Outdoor Learning, 21*(2), 172-183. https://doi.org/10.1080/14729679.2020.1769694

Bonney, R., Phillips, T. B., Ballard, H. L., & Enck, J. W. (2016). Can citizen science enhance public understanding of science?. *Public Understanding of Science*, *25*(1), 2-16. https://doi.org/10.1177/0963662515607406

Carrier, S.J., Scharen, D.R., Hayes, M., Sean, P.S., Bruce, A., Craven, L. (2024). Citizen science in elementary classrooms: A tale of two teachers. *Frontiers in Education, 9*. https://doi.org/10.3389/feduc.2024.1470070

Carrier, S.J., Thomson, M.M., & Tugurian, L.P., Stevenson, K.T. (2014). Elementary science education in classrooms and outdoors: Stakeholder views, gender, ethnicity, and testing. *International Journal of Science Education*, *36*(13), 2195-2220.

Carrier, S.J., Tugurian, L.P. & Thomson, M.M. (2013). Elementary science indoors and out: Teachers, time, and testing. *Research in Science Education*, *43*(5), 2059-2083.

Chandra, Y., Shang, L., Chandra, Y., & Shang, L. (2019). Inductive coding. *Qualitative research using R: A systematic approach*, 91-106. https://doi.org/10.1007/978-981-13-3170-1

CoCoRaHS. (n.d.). *About us. https://www.cocorahs.org/content.aspx?page=aboutus.*

Curran, F. C., & Kellogg, A. T. (2016). Understanding science achievement gaps by race/ethnicity and gender in kindergarten and first grade. *Educational Researcher*, *45*(5), 273-282. https://doi.org/10.3102/0013189x16656611

Davis, E., Palinscar, A. S., Arias, A. M., Bismack, A. S., Marulis, L., & Iwashyna, S. (2014). Designing educative curriculum materials: A theoretically and empirically driven process. *Harvard Educational Review*, *84*(1), 24-52. https://doi.org/10.17763/haer.84.1.g48488u230616264

Dillon, J., Rickinson, M., & Teamey, K. (2016). The value of outdoor learning: evidence from research in the UK and elsewhere. In T*owards a convergence between science and environmental education* (pp. 193-200). Routledge. https://doi.org/10.4324/9781315730486

Disinger, J. F. (1987). *Cognitive learning in the environment: Elementary students.* ERIC/SMEAC Environmental Education Digest No. 2, 1987.

Doan, S., Eagan, J., Grant, D., Kaufman, J. H., & Setodji, C. M. (2022). *American Instructional Resources Survey. 2022 Technical Documentation and Survey Results. Research Report.* RR-A134-14. In RAND Corporation. RAND Corporation. https://doi.org/10.7249/RRA134-14

Dunn, R. R., Urban, J., Cavelier, D., & Cooper, C. B. (2016). The tragedy of the unexamined cat: Why K–12 and university education are still in the dark ages and how participatory science allows for a Renaissance. *Journal of Microbiology & Biology Education*, *17*(1), 4-6. https://doi.org/10.1128/jmbe.v17i1.1049

Esch, R. K., Burbacher, E., Dodrill, E., Fussell, K. D., Magdich, M., Norris, H., & Midden, W. R. (2020). Citizen science in schools: Scientists' perspectives on promise and pitfalls. *Horizon Research, Inc.*

Explore Reports. (n.d.). EdReports. Retrieved March 2, 2024, from https://edreports.org/reports/science

Feille, K. (2021). A framework for the development of schoolyard pedagogy. *Research in Science Education*, *51*(6), 1687-1704. https://doi.org/10.1007/s11165-019-9860-x

Giamellaro, M. (2017). Dewey's yardstick: Contextualization as a crosscutting measure of experience in education and learning. *Sage Open, 7*(1). 1-11. https://doi.org/10.1177/2158244017700463

Harris, E., & Ballard, H. (2018). Real science in the palm of your hand. *Science and Children*, *55*(8), 31-37. https://doi.org/10.2505/4/sc18_055_08_31

Irish, T., & Kang, N. H. (2018). Connecting classroom science with everyday life: Teachers' attempts and students' insights. *International Journal of Science and Mathematics Education*, *16*, 1227-1245. https://doi.org/10.1007/s10763-017-9836-0

James, J. K., & Williams, T. (2017). School-based experiential outdoor education: A neglected necessity. *Journal of Experiential Education*, *40*(1), 58-71. https://doi.org/10.1177/1053825916676190

Jones, K. F. (2022). A citizen science freezing rain tree. In *Proceedings–Int. Workshop on Atmospheric Icing of Structures, IWAIS* (pp. 19-23).

Jones, G., Childers, G., Stevens, V., & Whitley, B. (2012). Citizen scientists: Investigating science in the community. *Science Teacher*, *79*(9), 36–39. https://doi.org/10.1080/21548455.2018.1475780

Krist, C., & Shim, S. Y. (2024). Which ideas, when, and why? An experienced teacher's in-the-moment pedagogical reasoning about facilitating student sense-making discussions. *Journal of Research in Science Teaching*, *61*(2), 255-288. https://doi.org/10.1002/tea.21908

Lackstrom, K., Farris, A., & Ward, R. (2022). Backyard hydroclimatology: Climate scientists contribute to drought detection and monitoring. *Bulletin of the American Meteorological Society*, *103*(10), E2222-E2245. https://doi.org/10.1175/bams-d-21-0157.1

Losey, J., Allee, L., & Smyth, R. (2012). The Lost Ladybug Project: Citizen spotting surpasses scientist's surveys. *American Entomologist*, *58*(1), 22-24.

https://doi.org/10.1093/ae/58.1.0022
Lost Ladybug Project. (n.d.). *About us.* http://www.lostladybug.org/about.php
Lowell, B. R., Cherbow, K., & McNeill, K. L. (2021). Redesign or relabel? How a commercial curriculum and its implementation oversimplify key features of the NGSS. *Science Education*, *105*(1), 5-32. https://doi.org/10.1002/sce.21604
Lloyd, A., Truong, S., & Gray, T. (2018). Place-based outdoor learning: More than a drag and drop approach. *Journal of Outdoor and Environmental Education, 21*, 45-60. https://doi.org/10.1007/s42322-017-0002-5
Lucky, A., Savage, A. M., Nichols, L. M., Castracani, C., Shell, L., Grasso, D. A., ... & Dunn, R. R. (2014). Ecologists, educators, and writers collaborate with the public to assess backyard diversity in The School of Ants Project. *Ecosphere*, *5*(7), 1-23. https://doi.org/10.1890/ES13-00364.1
Lynch, L. I., Dauer, J. M., Babchuk, W. A., Heng-Moss, T., & Golick, D. (2018). In their own words: The significance of participant perceptions in assessing entomology citizen science learning outcomes using a mixed methods approach. *Insects*, *9*(1), 16. https://doi.org/10.3390/insects9010016
Mahmoudi, D., Hawn, C. L., Henry, E. H., Perkins, D. J., Cooper, C. B., & Wilson, S. M. (2022). Mapping for whom? Communities of color and the citizen science gap. *ACME: An International Journal for Critical Geographies*, *21*(4), 372-388. https://doi.org/10.14288/acme.v21i4.2178
Marchante, E., López-Núñez, F. A., Duarte, L. N., & Marchante, H. (2024). The role of citizen science in biodiversity monitoring: when invasive species and insects meet. In *Biological Invasions and Global Insect Decline* (pp. 291-314). Academic Press. https://doi.org/10.1016/b978-0-323-99918-2.00011-2
Martin, S.C. (2003). The influence of outdoor schoolyard experiences on students' environmental knowledge, attitudes, behaviors, and comfort levels. *Journal of Elementary Science Education*, *15*(2), p. 51-56.
Mizokami, S. (2018). Deep active learning from the perspective of active learning theory. Deep active learning: Toward greater depth in university education, 79-91. https://doi.org/10.1007/978-981-10-5660-4_5
National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* National Academies Press.
National Science Teaching Association (NSTA). (2023). *Science Standards.* https://www.nsta.org/science-standards.
NGSS Lead States. (2013). Next Generation Science Standards: For states, by states. Washington, DC: The National Academies Press.
Oberle, E., Zeni, M., Munday, F., & Brussoni, M. (2021). Support factors and barriers for outdoor learning in elementary schools: A systemic perspective. *American Journal of Health Education, 52*(5), 251-265. https://doi.org/10.1080/19325037.2021.1955232
O'Donnell, C. (2023). *Exploring the Experiences of K-12 Science Teachers Using Citizen Science to Engage Student Learners: An Interpretive Phenomenological Analysis* (Doctoral dissertation, Northeastern University). https://doi.org/10.17760/d20483515
Pak, K., Polikoff, M. S., Desimone, L. M., & Saldívar García, E. (2020). The adaptive challenges of curriculum implementation: Insights for educational leaders driving standards-based reform. *Aera Open*, *6*(2), 2332858420932828. https://doi.org/10.1177/2332858420932828
Plumley, C. L. (2019). *2018 NSSME+: Status of elementary school science.* Horizon Research, Inc.
Quay, J., & Seaman, J. (2013). Outdoor education and indoor education. In *John Dewey and education outdoors* (pp. 13-44). Brill. https://doi.org/10.1007/978-94-6209-215-0_3

Riger, S., & Sigurvinsdottir, R. (2016). Thematic analysis. *Handbook of methodological approaches to community-based research: Qualitative, quantitative, and mixed methods*, 33-41. https://doi.org/10.1093/med:psych/9780190243654.003.0004

Rios, J. M., & Brewer, J. (2014). Outdoor education and science achievement. *Applied Environmental Education & Communication, 13*(4), 234-240. https://doi.org/10.1080/1533015X.2015.975084

Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context*. Oxford University Press.

Sadler, T. D. (2009). Situated learning in science education: socio-scientific issues as contexts for practice. *Studies in Science Education*, *45*(1), 1-42. https://doi.org/10.1080/03057260802681839

Schuttler, S. G., Sorensen, A. E., Jordan, R. C., Cooper, C., & Shwartz, A. (2018). Bridging the nature gap: can citizen science reverse the extinction of experience?. *Frontiers in Ecology and the Environment*, *16*(7), 405-411. https://doi.org/10.1002/fee.1826

Shah, H. R., & Martinez, L. R. (2016). Current approaches in implementing citizen science in the classroom. *Journal of Microbiology & Biology Education*, *17*(1), 17-22. https://doi.org/10.1128/jmbe.v17i1.1032

Sheppard, S. A., Turner, J., Thebault-Spieker, J., Zhu, H., & Terveen, L. (2017). Never too old, cold or dry to watch the sky: A survival analysis of citizen science volunteerism. *Proceedings of the ACM on Human-Computer Interaction*, *1*(PSCW), 1-21. https://doi.org/10.1145/3134729

Shume, T. J., & Blatt, E. (2019). A sociocultural investigation of pre-service teachers' outdoor experiences and perceived obstacles to outdoor learning. *Environmental Education Research*, *25*(9), 1347-1367. https://doi.org/10.1080/13504622.2019.1610862

Smith, P. S., Goforth, C., Carrier, S., Hayes, M. (2025). An emerging theory of school-based citizen science. *Citizen Science: Theory and Practice, 10*(1), 1-10. https://doi.org/10.5334/cstp.755

Szczytko, R., Carrier, S., & Stevenson, K.T. (2018). Impacts of outdoor environmental education on attention, behavior, and learning outcomes for students with emotional, cognitive, and behavioral disabilities. *Frontiers,* 3, 46. DOI: 10.3389/feduc.2018.00046.

Tan, E., & So, H. J. (2019). Role of environmental interaction in interdisciplinary thinking: from knowledge resources perspectives. *The Journal of Environmental Education*, *50*(2), 113-130. https://doi.org/10.1080/00958964.2018.1531280

Thorburn, M., & Marshall, A. (2014). Cultivating lived-body consciousness: Enhancing cognition and emotion through outdoor learning. *Journal of Pedagogy*, *5*(1), 115-132. https://doi.org/10.2478/jped-2014-0006

Vanhorn, S., Ward, S. M., Weismann, K. M., Crandall, H., Reule, J., & Leonard, R. (2019). Exploring active learning theories, practices, and contexts. *Communication Research Trends*, 38(3), 5-25. https://scholarcommons.scu.edu/crt/vol38/iss3/1

Vygotsky, L. S., & Cole, M. (1978). *Mind in society: Development of higher psychological processes*. Harvard University Press.