International Journal of Science Education

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tsed20

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To cite this article: Sarah J. Carrier, Lindsey H. Sachs, Jill M. McGowan, Meredith Hayes, P. Sean Smith, Christine L. Goforth & Sarah E. Safley (16 Feb 2024): Elementary teachers as collaborators: developing educative support materials for citizen science projects, International Journal of Science Education, DOI: 10.1080/09500693.2024.2311801

To link to this article: https://doi.org/10.1080/09500693.2024.2311801

Published online: 16 Feb 2024.

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION
https://doi.org/10.1080/09500693.2024.2311801

Elementary teachers as collaborators: developing educative support materials for citizen science projects

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ABSTRACT

Science education is an important component of a full education beginning in primary grades. In recent decades, research has identified young learners' rich knowledge of the natural world and their potential to connect with sophisticated science ideas. Elementary teachers face many challenges to implementing reform-based science instruction in their classrooms. Some teachers may choose to enhance their students' science experiences by introducing them to citizen science (CS) projects. Unfortunately, few CS projects offer substantial guidance for teachers seeking to implement the projects for instructional purposes, placing a heavy burdenon teachers. To address these burdens, our research team collaborated with Teacher Advisory Group (TAG teachers) during the development and revision of educative support materials for two CS projects. We present data about how the TAG teachers informed our CS support materials' revisions, how they implemented the two CS projects with and without educative support materials, and how they perceived their students' classroom and outdoor experiences with the CS projects. These data demonstrate the importance of including teachers' voices and experiences in reform efforts, particularly when trying to incorporate instructional elements that teachers may perceive as deviations from what they are expected to teach.

ARTICLE HISTORY
Received 2 August 2023
Accepted 24 January 2024

KEYWORDS
Primary/elementary science; citizen science; outdoor; educative curricula

Science education is a critical component of a full education (Appleton, 2013), beginning in primary grades (Roth, 2014). In recent decades, research has documented young learners' rich knowledge of the natural world and their potential to connect with sophisticated science ideas (Davis & Stephens, 2022; Eshach & Fried, 2005; National Research Council [NRC], 2007, 2012; National Academies of Science, Engineering, and Mathematics [NASEM], 2022). Unfortunately, the frequency and depth of science instruction in elementary schools pales in comparison to mathematics and reading instruction (Banilower et al., 2018; Plumley, 2019), and in order to provide students with significant science instruction, teachers must navigate time constraints and lack of resources,

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including curricula (Haverly et al., 2022). Some teachers may choose to enhance their science instruction by introducing students to citizen science (CS) projects (Jenkins, 2011).

When CS projects are incorporated in formal school settings, students have an opportunity to collect and make sense of the real-world data (Harlin et al., 2018; Jones et al., 2012). '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), yet of the hundreds of CS projects that exist, few offer substantial guidance for teachers seeking to implement the projects for instructional purposes, thus placing a heavy burden on teacher learning. One way to support the demands on teachers' learning and time is to develop educative instructional materials (Davis et al., 2017). Educative curricula are 'designed to promote teacher learning as well as student learning' (Davis et al., 2014, p. 25) by helping teachers both acquire content knowledge and build their pedagogical content knowledge (Arias et al., 2016; Davis et al., 2017). Recognising the potential for including CS in classrooms and acknowledging the need for teacher support, we designed educative support materials for two CS projects. In the process of designing and refining the CS projects' support materials, we recognised how teacher input helped us to tailor the materials to meet teachers' needs. The teachers' roles strengthened the support materials' potential for classroom application.

The work we describe here is part of a larger study investigating which features of curriculum support materials foster teacher learning, how the support materials shape the way teachers enact school-based CS, and the potential of school-based CS to positively influence student learning and student attitudes toward nature and science. Our participants in the present study are a small group of teachers who we call our teacher advisory group (TAG) with whom we collected data in the earliest stages of the project when we were designing and piloting the support materials. We present research here that documents the TAG members' experiences and how their experiences informed our support materials' revisions during these important initial stages.

Our larger study was influenced by three factors: the Next Generation Science Standards' (NGSS Lead States, 2013) recommendations to immerse students in 3-dimensional learning, the need to engage students frequently and purposefully with nature (Malone, 2008; Schuttler et al., 2019), and the potential for CS to involve elementary school students in collecting, analysing, and making sense of data to answer authentic scientific questions. Our ultimate research goals are to learn how best to assist elementary teachers' science instruction by incorporating CS projects in their classrooms.

Here, we report how the TAG teachers became integral collaborators for our project. In most cases, teachers in our study had never used CS projects for their instruction and in fact were unfamiliar with CS; thus we recognised the need to first introduce teachers to CS. In reviewing the literature on educative support materials development and CS project connections with formal education, we identified a dearth of research documenting teachers' contributions to the development of educative support materials for CS projects. Our research questions asked:

1. How did TAG teachers implement CS projects with and without educative support materials?
2. How did TAG teachers inform the educative support materials development and revisions?
3. What were TAG teachers' and students' classroom and outdoor experiences with CS?

In the following section, we present an overview of the benefits of elementary science education, teacher challenges, outdoor learning, CS, and a review of research on educative support materials.

Literature review

Elementary school science, or 'general science,' includes life, physical, and Earth science. In addition to teaching all elementary school subjects, most elementary school teachers are tasked with knowing and teaching students about each of these areas of science (National Science Teachers Association [NSTA], 2020; Nowicki et al., 2013). Features of effective science instruction begin with teachers identifying students' existing knowledge (Sawyer, 2006), using science practices to develop students' conceptual understandings (Hennessey, 2003), designing classroom investigations that respond to students' questions (Michaels et al., 2007), providing students with opportunities to engage in scientific argumentation (Jin & Kim, 2021; Sandoval et al., 2019), helping students learn ways to represent data and incorporate models (Evagorou et al., 2020), and providing opportunities for learning the nature of science (Akerson et al., 2010; Akerson & Abd-El-Khalick, 2003). Relatedly, effective science instruction helps students learn to ask questions, collect, and make sense of data (NRC, 2012; NGSS Lead States, 2013), yet these types of instruction are not frequently found in elementary classrooms (Banilower et al., 2018; Plumley, 2019).

While science education in early grades has significant benefits (Black et al., 2017; Granger et al., 2012; NRC, 2005; Outhwaite et al., 2022), there are both institutional and instructional challenges that impact science education in elementary schools (Sandholtz & Ringstaff, 2011). In the United States and globally, less time is spent teaching science in elementary school classrooms when compared to mathematics and English language arts (ELA) (Murphy et al., 2007; Plumley, 2019; Uçar, 2009). In addition to institutional policies that limit time for science teaching in primary grades, elementary school teachers are often unsure of their abilities to effectively teach science.

Institutional challenges

Institutional policies focusing on accountability and testing have imposed limits on science instruction that include instructional time (Allen et al., 2007; Carrier et al., 2013; Romance & Vitale, 2012) and lack of resources or materials (Bradbury & Wilson, 2020; Milner et al., 2012).

Time constraints

In today's elementary classrooms, science instruction is limited in both time and relevance compared to other subject areas instruction (Griffith & Sharmannm, 2008;

Plumley, 2019; Romance & Vitale, 2012; Trygstad, 2013). Milner and colleagues (2012) collected quantitative and qualitative data from 502 practicing teachers regarding their beliefs about science teaching, and teachers shared that their administrators deeply reduced their science instructional time in order to spend more time teaching reading and mathematics. The 2018 Report of the National Survey of Science and Mathematics Education (Banilower et al., 2018) found that teachers in lower elementary classrooms spend an average of 18 min each day on science as compared to more than 57 min on mathematics and 89 min on reading instruction. In one study, 5th grade science teachers reported limited time for teaching science properly due to a focus on tested subjects; relatedly, these teachers described an institutional emphasis on using materials and activities from pre-designed science kits associated with concepts directly linked to standardised tests (Carrier et al., 2013). While science is tested in most US states, the test scores are infrequently included in accountability measures (Achieve, 2019), and there are inconsistencies in science instructional materials. In the state where the present study took place, teachers are provided with state science standards, but the standards are not aligned with NGSS (NGSS Lead States, 2013). In addition, each district or school is responsible for science curricula, and teachers are often responsible for finding their own, thus leading to this project's development of CS curriculum materials to support participants' elementary science instruction.

Resources and materials

Teachers have described challenges in executing effective science lessons when they lack resources. Bradbury and Wilson (2020) interviewed thirteen elementary teachers who expressed positive feelings about teaching science in their classrooms, yet they felt constrained by the lack of available resources. Milner and colleagues (2012) similarly found that teachers valued science instruction for their students, but they reported a lack of resources and materials to support their science instruction. These disparities are especially pronounced in schools with a high level of students on free and reduced lunch, an indicator of low income (Smith et al., 2013). Without sufficient resources, teachers report feeling constrained in the quality and outcome of the instruction they are able to provide students.

Instructional challenges

Elementary school teachers are trained as generalists, and in addition to teaching mathematics, literacy, and social studies, most elementary teachers are also expected to teach all areas of science (NSTA, 2020). Elementary teachers need a breadth and depth of content area knowledge, and they must also incorporate a host of instructional strategies to communicate the wide range of subjects with diverse populations of students. In this context of high demands that teachers face, researchers have found that elementary teachers report limited science content knowledge and low self-efficacy in teaching science (Appleton, 2013; Carrier et al., 2013; Dorph et al., 2011; McDonnough & Matkins, 2010; Plumley, 2019). Science curricula that provide not only lesson plans for students but also support teachers' knowledge of content and effective instructional practices are identified as educative curriculum materials (Davis et al., 2017) that we refer to in our study as educative supports.

Educative curriculum materials

Educative curriculum materials are designed to help teachers provide high-quality educational science instruction in their classrooms that integrate science content with science practices (Davis et al., 2017). Use of such materials can help teachers transition from traditional, teacher-centred science instruction to reform-based, student-centred instruction. Davis et al. (2014) describe educative curriculum materials as 'designed to promote teacher learning as well as student learning' (p. 25). Such curriculum materials include features such as content boxes, teacher narratives, charts and graphs, guides for student work, and detailed graphics for other content support (Arias et al., 2016; Davis et al., 2014, 2017). These materials can help teachers acquire content knowledge as they build their pedagogical content knowledge (Arias et al., 2016; Davis et al., 2014, 2017).

Davis and colleagues (2017) also recommend educative support materials to help teachers learn to engage students in science practices. Findings provided by Arias et al. (2016) suggest that when designers of educative curriculum materials are purposeful in creating materials, it 'may support the creation of rich learning opportunities called for by new reforms, allowing for ambitious science teaching and learning' (p. 444). In addition to identifying the need for instructional time and educative curriculum materials to improve science education, researchers have explored ways that including instruction in the outdoors can promote student learning.

Outdoor education

Researchers have examined the benefits of moving student learning beyond the four walls of the classroom to include outdoor instruction. In addition to providing students with opportunities to increase their content knowledge through engagement with the natural world, researchers have identified physical and mental health benefits to situating instruction in the outdoors, including motivation (James & Williams, 2017; Koto & Susanta, 2019), social and cognitive benefits (Kuo et al., 2019), critical thinking/reflection (Mayer et al., 2009), and improved attention and behaviour for students with emotional, cognitive, and behavioural disabilities (Szczytko et al., 2018).

Despite the positive outcomes associated with outdoor education, teachers face barriers similar to those associated with elementary science teaching in general (as described above): lack of time, lack of administrative support, testing pressures, and a need for professional development. In an examination of CS in European countries, the authors recognise that teachers:

> play a crucial role in successfully integrating such projects into their classrooms and schools. That some teachers may lack confidence in their own general level of scientific content knowledge and scientific literacy can considerably impede this process – for example, issues of content knowledge could arise on projects that require teachers to explore outdoor environments. (Roche et al., 2020, para. 7)

Traditional indoor lessons are conducted in elementary science classrooms more often than authentic outdoor learning experiences (Carrier et al., 2014; Largo-Wight et al., 2018). In one study that examined teachers' proposed outdoor instruction over the span of a school year, despite initial intentions, teachers reported they often resorted to traditional indoor science instruction because they viewed outdoor instruction time as ‘in addition to’ rather than as ‘a part of’ their instruction goals. The teachers lamented that there was not enough time available to cover all necessary (tested) content while also utilising the outdoors (Carrier et al., 2013; Eick, 2012). Involving teachers in curriculum development has potential to build teachers’ confidence in teaching science and extending science instruction to the schoolyard.

Schoolyard science

In comparing field trips (e.g. to nature centres) with schoolyard activities, schoolyard options relieve teachers of some logistical concerns such as time, transportation, and costs (Cronin-Jones, 2000; Martin, 2003). Elementary school students frequently feel a sense of familiarity and belonging in their schoolyards, and lessons on school grounds lend themselves to ongoing observations and data collection (Boss, 2001; Carrier & Stevenson, 2017; Cronin-Jones, 2000). ‘Continuous, repeated activities with recognizable natural surroundings can have a stronger effect on student learning than occasional experiences in novel nature areas’ (Martin, 2003, p. 52). In the schoolyard, students can participate in ongoing observations of weather patterns, seasonal changes, and life cycles – all connecting science learning to students’ lives (Jenkins, 2011). Authentic data collection in the schoolyard and sharing data with the science community through CS projects has the potential to help teachers capitalise on these mutually beneficial connections.

Citizen science

Data collected by non-professional scientists and shared with the science community is commonly called ‘citizen science’ (CS); also ‘community-based participatory research’ or ‘public understanding of science’ (Bonney et al., 2009; de Sherbinin et al., 2021; Kermish-Allen, et al., 2019). Engaging the public in the collection and interpretation of data, much as scientists do, bridges professional science with non-professionals geared toward specific science content. In addition, Bonney et al. (2016) suggests that ‘Citizen science is engaging, can lead to increased understanding of science content, and sometimes leads to knowledge of the process and nature of science’ (p. 14). Because of this, some educators are turning to CS to supplement their science instruction and provide their students with opportunities for authentic, inquiry-based scientific experiences within a community context (Esch et al., 2020).

Authentic science data collection

One benefit of CS participation is the opportunity for engaging in authentic science data collection. Because of geographic spread and time-expansive data collection, there are not enough science professionals and researchers to collect data on the same scale as is possible through CS projects. While some question the quality of data collected by non-professionals, Bonney and colleagues (2014) explain that ‘with appropriate protocols, training, and oversight, volunteers can collect data of quality equal to those collected by experts’ (p. 1496). Including the public in science endeavours offer opportunities for expanding science awareness and literacy (Nascimento et al., 2014). Such opportunities support recommendations for providing students with experiences that align with those of professional scientists (NRC, 2012) and that connect with students’ lives (Jenkins, 2011; Stuckey et al., 2013).

Collaboration with schools

When CS projects are incorporated in formal school settings, students have opportunities to engage in authentic science data collection and sense making (Green & Medina-Jerez, 2012; Harlin et al., 2018; Jones et al., 2012). In doing so, students can see how their work contributes more broadly to science missions (Esch et al., 2020). Fee and Trautmann (2012) reviewed a CS project titled BirdSleuth that emphasised the authentic data collection upper elementary and middle school students engage in, which can 'boost academic achievement while helping students develop stronger ties to their community and appreciation for the natural world' (p. 63). Further, when CS projects are conducted on the school grounds, students can reap the benefits of outdoor education described above.

The Global Learning and Observations to Benefit the Environment (GLOBE) project is a CS program used in elementary settings that has been studied extensively. GLOBE is a cross-curricular exploration connecting students with scientists from around the world sharing climate data related to their local environments. Following students' participation in the GLOBE project, Bonney et al. (2016) reported that students used science process skills such as making inferences at higher rates than students who had not participated in GLOBE activities. Bonney and colleagues also explain the importance of extensive teacher and student training in data collection and interpretation to ensure data quality when incorporating CS projects such as GLOBE in schools.

Another CS project used in elementary schools, eMammal, supports student learning about mammal diversity within their communities. In an examination of students' experiences with eMammal, researchers reported students' excitement about their contribution to scientific research (Schuttler et al., 2019). The impacts of this project were far-reaching and 'permeated throughout their communities' (p. 77) with student sharing of photos, graphs, and presentations for government officials. Through content-aligned CS projects in the classroom, students can engage in scientific data collection and sense-making, as they learn about the practices of professional scientists. CS projects' potential to enhance elementary school instruction strengthens when they connect with content standards, integrate across content areas, and include fully-developed, aligned teacher supports (Esch et al., 2020). At present, few CS projects include support materials for teachers, which places a substantial burden on teachers who want to integrate CS projects into their science instruction. The present study examines how educative supports designed for two CS projects influence teachers' implementation of the projects. We document our TAG's interactions in CS projects first without and then with CS support materials, and we explore the relationship between teachers and curriculum. Also exploring the contributions of context and students, we position this study with an acknowledgement of the context of schools and the challenges of science education in elementary schools.

Theoretical framework

As we examine how our TAG teachers interpreted and enacted our CS educative support materials in their classrooms, we frame our current research using Remillard's (2005) teacher-curriculum relationship model. Remillard identified key constructs of a teacher-curriculum relationship that assumes a 'participatory relationship between the teacher and the curriculum' (p. 235). In this framework, Remillard explains that the degree or fidelity of teachers' instruction with the intended curriculum must be clearly defined. Remillard's model focuses on the participatory relationship between teacher and curricula and how this relationship influences the teachers' planned and enacted curricula. Additional components of Remillard's model are students and context. As seen in Figure 1, we have adapted Remillard's model by elevating the roles of Contexts and Students, which we represented as key constructs influencing teacher decisions for instruction. We include these constructs in our discussion of teachers' interpretation and enactment of curricula.

Methods

Context

Our goals for the larger study were to collect data on how teachers in the U.S. might incorporate CS projects in their classrooms to enhance their science instruction and to identify what types of support materials for CS promote teacher and student learning. Our first step was to identify features of educative materials that could support teachers' implementation of CS projects, particularly those that encourage students' participation beyond data collection and provide meaningful sense-making opportunities. Our research team developed instructional support materials for two existing CS projects: Community Collaborative Rain, Hail, and Snow (CoCoRaHS) Network (https://www.cocorahs.org/) and Lost Ladybug Project (LLP) (http://www.lostladybug.org/). We chose these two projects because of their alignment with our state's 5th grade science standards to guide student learning of ecosystems and weather. We chose to complement the prior elementary school teaching experiences of our research team with the experiences of practicing teachers that we called our teacher advisory group (TAG). We asked these teachers to implement the CS projects in their 5th grade classrooms, first

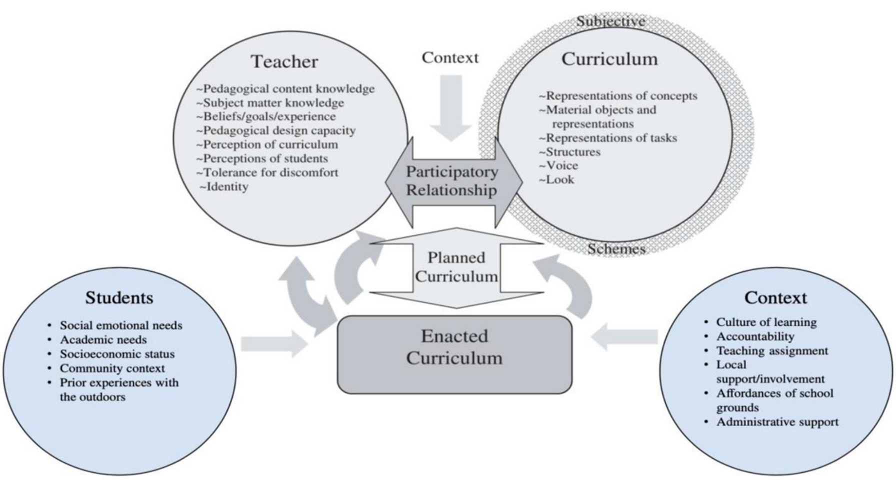

Figure 1. Framework for relationship of teacher, curriculum, students and context (adapted from Remillard, 2005).

without our instructional support materials and then using our instructional support materials.

We spent the first year developing educative support materials for both CS projects, and during our development process in the spring of that first school year, we asked the TAG teachers to implement the CS projects in their classrooms 'as is,' meaning as if they had come across the CS project websites on their own and without access to the materials we were developing. In late spring of that first year, we shared our newly developed support materials with TAG teachers and asked them to provide feedback on the amount of material, feasibility of implementation, sufficiency of support materials, and tone. We used their feedback to finalise the support materials that we shared in person with them during summer workshops. In Year 2, TAG teachers again implemented the two projects, this time pilot testing the support materials for both projects throughout an entire school year. We met with TAG teachers in monthly virtual meetings to get their feedback, in addition to interviewing them individually four times throughout the year. The TAG teachers' experiences and reflections from the meetings and interviews informed our revisions to the materials. Figure 2 represents the timeline of the larger study (in progress); the present study with the TAG teachers was concentrated in Years 1 and 2.

The support materials were designed as monthly 'engagements' (i.e. opportunities for students to engage with CS data they and others had collected) that build as the school year progresses. With the goals of regular data collection, the teachers are expected to dig deeply into the projects once or twice each month. Each month's support materials include objectives, science and mathematics standards alignment, a summary of suggested activities, a descriptive scenario of a fictional teacher's implementation of that month's classroom activities, and multiple resource materials. Examples of resource materials include connections with literacy, mathematics, and social studies; professional scientists' use of CS data; science and mathematics content knowledge for teachers; and suggestions of teaching strategies (see Table 2). Because we did not have a chance to observe in classrooms (due to COVID restrictions), the TAG teachers' narrative accounts were especially valuable to help us learn about their classroom implementation of the CS projects.

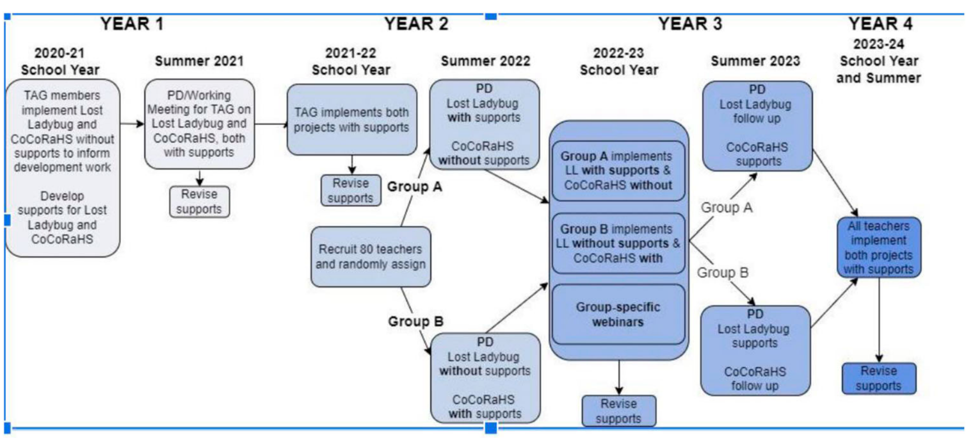

Figure 2. Study timeline.

Table 2. Key features of TL4CS support materials.

Feature	Description
In a Nutshell	Overview of content focus for the month's activities
Narrative	Descriptive text detailing a teacher's approach
Science Content and/or Practices	NGSS and state standards addressed this month
Guides for Outdoor Learning	Recommendations for preparing students for the outdoor classroom, planning for weather, student resources, and movement
Mathematics	Mathematics addressed this month
Literacy	Literacy practices and connections
Assessment	Assessment opportunities/suggestions
Citizen Science Connection	Supports for connecting to the work of citizen scientists and their contributing science data
Extensions	Opportunities for extending learning of the month's activities focus

Data and data analysis

In addition to documenting feedback from the TAG teachers via monthly meetings throughout year 2, we conducted interviews in June 2021, October 2021, January 2022, and June 2022 – a total of 19 interviews. These data highlight the value of our TAG members' insights. Their contributions to our research include (1) informing our support materials' development and revisions, (2) helping us understand how teachers interpret and implement CS projects with and without educative support materials, and (3) offering a window into students' classroom and outdoor experiences with CS.

Each of the interviews was transcribed, and interview questions were used to develop initial coding themes to identify TAG teacher statements related to the research questions. Three researchers reviewed a sample of interviews to identify statements that illustrated each TAG teacher's experiences implementing CS both with and without the support materials, their impressions of students' experiences with CS, and with outdoor learning. The researchers' respective interpretations of teachers' statements were compared for alignment with the themes. Additional patterns were identified and following discussions, themes were added that include TAG teachers' discussions about how the CS experiences expanded beyond science to other subject areas, the importance of support materials' connections with standards, descriptions of school administrator support, and TAG teachers' impressions of how support materials were helpful or needed revisions (see Table 1).

Two additional interviews were analysed using the revised themes to determine inter-rater reliability over 80%. The remainder of the interviews were then coded by one of the three researchers and are next presented in response to the research questions.

Findings

Research question 1

Our first research question asked, 'How did TAG teachers implement CS projects with and without educative support materials?'

Tag experiences without support materials

We begin by presenting the TAG teachers' descriptions of their initial implementation of the two CS projects in their classrooms *without* our support materials. Many TAG

Table 1. Themes, descriptions, and sample quotes.

Themes	Description	Sample Quotes
Without support materials	TAG teachers' descriptions as they first incorporated CS projects in their classrooms prior to having TL4CS support materials.	*It would be great to have some kind of guidance as to what would be most beneficial for a fifth grade teacher to look at and pull up ideas for how to use that with your students.*
TAG – CS with support materials	TAG teachers' experiences instructing using TL4CS support materials.	*I do like the one called the Narrative, the one that is like the pretend teacher. I think that one's really helpful. It kind of puts everything into like a true situation, even though it's maybe not true, but it reads like it is, and I think that's helpful*
Teachers' experiences with CS Subthemes: Administrators Standards	TAG teachers' impressions of CS in their classrooms	*The big thing is just having connections to larger organisations or, when you're doing stuff at school, it's always important to have that connection of why am I doing this? Why does it matter?*
Students' experiences with CS	TAG teachers' descriptions of their students' experiences with TL4CS CS projects	*They loved it. The rain gauge thing with just being out in our courtyard, it's right there by our cafeteria. So like it was something tangible.*
Teacher and student experiences with the outdoor learning	TAG teachers' descriptions of their students' experiences in the outdoors.	*The kids love it and I think it's so good for them. So to me that's been like number one benefit for the children is just doing outdoor learning*
Student experiences across subject areas	TAG teachers' descriptions of their students' interdisciplinary connections across subjects	*I think that kind of helps students to think about it a lot more when it's not just kind of an isolation within science class or for math.*
TAG reflections of support materials	TAG teachers' descriptions of their own experience with the TL4CS educative support materials	*I definitely feel like it's better, I'm implementing it better with the use of this stuff, whereas I never had time to look through the websites to probably use them well or better than I did last time.*

teachers expressed their frustrations implementing the projects. One TAG teacher, Courtney (all names are pseudonyms), commented on the difficulty of trying to teach herself about the two projects saying, 'I need more time … to explore the [CS projects'] websites and the uses, just how to seamlessly put it into the curriculum.' Only one teacher, Sandy, knew about CS and she was familiar with CoCoRaHS, but she had not explored its website nor planned for student engagement beyond collecting and recording rain gauge data. Sandy agreed with Courtney by saying,

> There's a lot on the CoCoRaHS website, and I just haven't sat down and looked at all of it yet. It would be great to have some kind of guidance as to what would be most beneficial for a fifth grade teacher to look at and pull up ideas for how to use that with your students.

Sandy went on to describe her needs for 'definitely more explicit instruction on the website.' Janet explained her interactions with the project websites, 'I was hoping for more kind of lesson planning ideas or things like that.' As we collected these TAG comments, we were simultaneously developing support materials. The teachers' comments often confirmed that the materials we were developing would support their needs, such as Sandy's comment 'how to use it beyond just recording your data.'

Tag experiences with support materials

In Year 2, our interviews captured the TAG teachers' initial interactions *with* the support materials for both projects. Laura described her initial process learning about the monthly support materials, 'I go through and I read it all, you know, from front to end, and then I pick and choose because there's a lot of material there.'

Although teachers' levels of implementation with the projects in their classrooms varied, there was evidence that all TAG teachers incorporated both projects with their students to some extent. Teachers often chose to focus more intently on one project over the other from month to month due to factors such as seasonal changes in weather (and its effect on the prevalence of ladybugs) or the district's timing of certain standards-based science units. Interestingly, while Sandy had prior experience collecting rain gauge data for CoCoRaHS, she reflected on how the support materials impacted her instruction:

> I love the resources … I had CoCoRaHS for I don't know how many years before this project, and I never really implemented it other than having students report the data. I didn't implement it where every child was touching it in some way, and this [the support materials] has given me a framework to let me see how I could do that.

Courtney also described how the support materials expanded her own classroom applications beyond data collection by providing 'other ideas for graphing and incorporating it into instruction.' Courtney further explained how portions of support materials helped her by

> seeing how it's going to play out in the classroom and what that actually looks like really helped … me know how much time I'm going to need or whether it's going to be feasible in my classroom at all.

Sandy explained how the support materials would be helpful to other elementary teachers. 'I like the resources … because a lot of elementary teachers don't have the science knowledge … It's not their favorite thing to teach.' In addition, Laura described how both CS projects connect with content that they already teach, which was a major reason for our selecting these two CS programs for this research:

> As with CoCoRaHS, [LLP] definitely ties in perfectly with our curriculum that we have to teach when it gets to ecosystems. It's a really nice review from fourth grade animal adaptations, and then it ties into fifth grade about what's affecting food webs in the ecosystems.

In consideration of the context of schools, we featured explicit direct connections to standards in our support materials. Janet described how connections with standards across disciplines helped her justify the project for her administrators, 'The science or the math standards connections, those were certainly helpful too, and that was helpful for me when I was talking to administration and they'd [ask], "Tell me why you're doing this [CS project activities]."' As framed in

In addition to science and mathematics connections, the support materials include connections to literacy and social studies. We found that these interdisciplinary connections allowed teachers to more readily incorporate the project throughout the school day. In a December 2021 TAG meeting, after using the support materials for four months, Laura announced,

> I had the best lesson when we compared fall [rain gauge] data to other [CoCoRaHS] stations in our state, and I did as it was outlined in the narrative [portion of the support materials]. It tied in social studies [what they learned in 4th grade about the state], math, and science. It was like one of those dream lessons where you are making all these connections. It was fantastic!

Research question 2

Our second research question asked, 'What were TAG teachers' contributions to educative support materials use and revisions?'

Tag teachers' recommendations for TL4CS support materials' revisions

As the TAG teachers implemented the CS projects with their students, their feedback on how they used the support materials provided insight into their interpretations and implementation. TAG comments led us to refine our materials to address their expressed needs, such as Sandy's

> I don't think our kids understand really how ladybugs are important to the environment. So to be able to pull that in and then relate it to other parts of the ecosystem, I think will be a good thing to have.

In response to Sandy's and other TAG teacher comments, we incorporated additional supports (e.g. callout boxes with informational text and images) related to ladybug roles in ecosystems (5th grade science standards) and life cycles into our Lost Ladybug Project materials. As Courtney initially reviewed the CoCoRaHS support materials, she suggested that we include 'more activities or suggestions or background information that would fit more in our weather unit.' Similarly, Laura suggested 'maybe a walk-through with the websites, to see what's available … I'm probably not using everything that would be helpful.' To address Laura's and other TAG teacher comments, we added a media guide with a list of resources for project-wide support.

The TAG teachers also provided insight into the support materials usability and their interpretations of the broader section labels. Each month's materials followed the same format and labels for each section. We had initially titled the first section 'Description' that provides an overview of the proposed monthly engagements. It was followed by a 'Narrative' section that presents a scenario of how an imaginary teacher implemented the project with students. Courtney said, 'The term 'Description' is kind of misleading. So, I look at it as that's the essential activity, the main activity for the month.' In response to this comment and other similar comments, we changed the 'Description' heading to 'In a Nutshell,' the new heading suggested by one of our TAG teachers, to capture the intent and content of that section. Though a cosmetic change, it helped teachers navigate the support materials better and find what they needed quickly, which was important given teachers' limited time for planning.

The TAG teachers' comments highlighted the importance of some of the support materials' features. As Janet interacted with the materials, she appreciated that the educative support materials were not scripted curricula saying, 'I guess seeing this more as a resource instead of like a regimented program.' Laura explained that while the supports include both science content and instructional strategies, the materials encourage teacher autonomy: 'Knowing that we had the freedom to use materials in the way that worked best for us was wonderful … I thought they were excellent as far as teaching strategies, so not just science content but also teaching methods.' The TAG teachers' descriptions of their respective strategies for interacting with the support materials were helpful for our team. For example, Laura explained:

> I kind of pick and choose and mesh together what I think is gonna work for me in my class, and then I take it and put it into a form that's gonna work for me … I love the pictures that have graphs or the charts. I like having that visual. It gives me an idea. That's pretty usually how I use those month-by-month pages.

Sandy appreciated 'All the objectives are right here up in a tab,' and she went on to say 'The teacher's narrative can be very helpful.' Sandy reinforced the need for teacher support saying, 'I like the resources that have been added in. I think it's good because a lot of teachers, especially elementary teachers, don't have the science knowledge.'

Research question 3

Our third research question asked 'What were TAG teachers' students' classroom and outdoor experiences with CS?'

Classroom learning

Our adaptations to Remillard's theoretical framework emphasise *context* and *students* as key constructs, and the influences of both on teachers' instructional decisions were made clear. When we asked TAG teachers about challenges of including CS projects in their classrooms, the common themes they named and that referenced the *context* of schools were accountability pressures, the related need for administrative support, and lack of instructional time for science. In June 2022, after implementing the CS projects for a full year with the support materials, Janet explained her, 'You have to follow the state curriculum, and then you have this pressure of testing for both those subjects [reading and mathematics] … I hate to always come back to the same old thing, but it's instructional time.' Janet elaborated on the importance of administrator support, 'The main thing is the principal needs to be willing to give teachers the time. The outdoor time is necessary too.'

In addition to the importance of administrative support, the TAG teachers shared the importance of students' enthusiasm to encourage their instructional decisions. In January 2022, after the TAG teachers had been using the support materials in their classrooms for five months, Courtney described the value of students' participation in CS as 'feeling part of something bigger – seeing how science is not just a classroom subject,' and in June 2022 Courtney said, 'They [CoCoRaHS and LLP] are great projects. They do take time, and you have to be willing to give that time to it. But they do make science more real for the kids.' In January 2022, Janet explained the value of CS for students as 'making science seem attainable and something that everybody can do. It's not just something that's done by a doctor in some lab or something.' In June 2022, Janet elaborated how students 'really learn and understand these concepts, instead of just sitting there learning all these kind of abstract vocabulary terms, like learning it in the real world, so I think it had a huge impact.'

Outdoor learning

In October 2021 as TAG teachers began using TL4CS support materials, when asked about the benefits of the CS projects, Laura said 'Well, number one is outdoor learning. Outdoor learning is a challenge and not done a lot as teachers, and it's a whole new ball game. The kids LOVE it!' In January 2022, Janet said, 'But the big thing is [CS projects] get kids excited about their time outside … and increases awareness.' Courtney also described how the projects' outdoor time enhanced student observations:

> They became more observant outside in nature. They would notice other things beyond ladybugs, and that would carry over beyond whole class search times; they would be more inquisitive and more observant of the little things and the big things of nature at recess and outside.

During a workshop in summer 2022, Laura also expressed her appreciation of students' outdoor learning, 'I think another benefit for my students has been seeing how learning science for them is not just what they do in the classroom.'

Discussion

As teachers interact with new curriculum materials, they require support in interpreting and implementing the new materials (Carl, 2005; Remillard, 2005; Shawer, 2017). CS projects offer opportunities for teachers to provide their students with rich science experiences with data collection and analysis and connect to students' lives (Jenkins, 2011; Roche et al., 2020). Yet teachers who choose to incorporate CS in their science instruction must be willing to devote significant time and effort to learn about the projects and to learn how to align the CS with their instructional goals (Harlin et al., 2018; Roche et al., 2020). In the present research study, one of our goals for providing teachers with educative support materials for two CS projects was to reduce the time and effort required for their implementation of CS in their classrooms. We situated our development of educative curriculum materials in prior research including Davis et al. (2017) who recommended:

> Curriculum designers should support multiple domains of teacher knowledge and practice, including subject matter knowledge and pedagogical content knowledge as well as associated teaching practices for supporting the content and disciplinary practices students are learning (p. 294).

Remillard (2000) identified the need for curricula to adapt to teacher needs, and Cervetti and colleagues (2015) documented how educative curriculum can positively influence teachers' instructional practices. Grossman and Thompson (2008) further identified how educative curricula provide opportunities for teacher learning of both subject matter knowledge and pedagogical content knowledge. In consideration of prior research, we further recognise that teachers adapt curricula depending on their own needs, the curricula, and their context (Davis et al., 2016). Such enacted curricula teaching decisions can offer curriculum developers insight into important features of curricular design. For all these reasons, we thought it was essential that we include teachers in developing our educative support materials.

Key features that influence the opportunities teachers provide for their students' engagement with science include the individual teacher, the curricula, and the participatory relationship between the two (Remillard, 2005). This relationship informs how teachers interpret the planned curricula and their resulting enacted curricula. As we examined the participatory relationship between the TAG teachers and our TL4CS support materials, we documented teachers' various degrees of fidelity in using various features of TL4CS support materials in their instruction. As Remillard (2005) pointed out, fidelity of curriculum may be a misleading construct, and identifying a desired enactment of curriculum is complex. Importantly, we recognised that the interactions of the teacher-curriculum relationship are significantly informed by teachers' perspectives, school contexts, and students. The data presented here emphasise the importance of including teachers in the development of instructional materials. Teacher voices and input are invaluable, and including teachers in curriculum development increases the likelihood of curricula materials' accessibility and uptake.

In our study, we valued the TAG teachers' ongoing feedback as they implemented two CS projects in their classrooms, first *without* educative support materials and then *with* our initial drafts of the support materials. This window into TAG teachers' classroom experiences with CS projects greatly informed our materials' development and revisions, as the TAG teachers offered many concrete suggestions for improvements based on their experiences with the materials. Our collaborations with the TAG teachers reinforce the potential for CS projects to enhance much-needed science instruction in elementary school classrooms (Banilower et al., 2018; Davis, & Stephens 2022; Jones et al., 2012; NASEM, 2022; Plumley, 2019). The TAG teachers described the ways that these CS projects helped students recognise how their collected data contribute to the field of science (Bonney et al., 2014; Esch et al., 2020) and how student experiences in their schoolyards enhanced their connections to nature and the outdoors (Carrier et al., 2014; Carrier & Stevenson, 2017; Koto & Susanta, 2019; Kuo et al., 2019; Malone, 2008; Tugurian & Carrier, 2017). In addition, each of the TAG teachers mentioned their intentions to continue with the CS projects and use of the support materials in the coming year, suggesting that their roles as collaborators on these projects also resulted in lasting change in their classroom practices. This outcome further reinforces the importance of involving teachers in the creation of educative support materials.

Implications

The TAG teachers played a critical role in the development of TL4CS educative support materials for two CS projects. By comparing the teachers' efforts to include CS first *without* and then *with* the support materials, we were able to identify how the educative curriculum materials enhanced teacher knowledge and informed teachers' instructional decisions. Teachers are the consumers and enacters of curricula, so curriculum developers who consider teachers' voices and uses of the materials are better able to meet the needs of both teachers and their students. CS projects offer opportunities for authentic data collection and sense-making and, when combined with educative curriculum materials that support teachers' content and instructional practices, there is rich potential for improved science instruction and student learning.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by National Science Foundation [grant number 2009212].

Ethics statement

This research met ethics requirements with Institutional Review Board approval # 0004953.

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