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Rural Elementary Teachers' Computational Thinking Self-Efficacy Through Community-Based Citizen Science

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ABSTRACT

While both citizen science engagements and computational thinking practices can mutually support student ownership in the science classroom, both face similar challenges to adoption in that they require teachers to openly position themselves as learners alongside their students. This dual role—as a teacher and as a learner—poses self-efficacy challenges that may preclude teachers from exploring these important pedagogical tools and perspectives in their classrooms. We present a cross-case analysis of three experienced teachers in rural elementary and middle schools as they integrate computational thinking in a year-long, student-led community-based citizen science project. Drawing from interview data, we illustrate how teachers' capacity to embrace their role of co-learners alongside their students redefined "mastery experiences" of teaching self-efficacy. Specifically, the case teachers evaluated their successful use of computational thinking within the community-based citizen science program in ways that valued student curiosity and discovery over mastery of content. In this way, their self-efficacy for using computational thinking developed when they saw and shared these activities in themselves and their students. We further illustrate how contextual contributors of the professional development program and their rural schools and districts contributed to their comfort in experimenting with new instructional approaches, which helped them to build the mastery experiences that fueled further exploration of computational thinking within their classroom's community-based citizen science investigations.

KEYWORDS

Community-based citizen science; computational thinking; professional development; rural; self-efficacy

Citizen science learning experiences—in which learners collect data that is shared across networks of investigators—may support developing science identities, knowledge, and skills (Phillips et al., 2018). Given its tie to large data sets and real-world issues, citizen science and community citizen science¹ lends itself to implementing computational thinking (CT) as learners manage and make sense of data (Christensen, 2023). This approach offers a "transformative" learning experience (Roche et al., 2020) by engaging learners throughout the process of identifying and solving local problems. Yet, a challenge to implementing

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¹"Citizen science" has attracted scrutiny for its political connotations of citizenship as a criteria for engagement, leading some to favor "community science" (Cooper et al., 2021). However, "community science" is paradigmatically grounded in community needs and action for social change—a component that is often missing in projects described as "Citizen science" that serve the interests of organizations (Cooper et al., 2021). Thus, "Citizen science" may apply to public-engaged scientific research more broadly, while "community science" is community-centric. When we speak of the project that is the focus of this paper, we refer to "community-based citizen science" to reflect the community-grounded nature of the work, reserving the "community science" term for activism-oriented projects.

citizen science and CT is teacher preparation. In citizen science, teachers and students simultaneously learn the context of the issue and the associated scientific content (Trumbull et al., 2005), which may conflict with how teachers see themselves as knowledge communicators (Gray et al., 2012). In CT, teachers may have unclear guidance on how to integrate CT outside of a computer science classroom (Yadav et al., 2014). In cases when CT is integrated, its authentic utility throughout the unit may not be intuitive, leading to the selective application of CT concepts (Ketelhut et al., 2020).

Such challenges become pronounced in rural contexts where removed from major university systems, educators infrequently have access to high-quality professional development (PD) (Glover et al., 2016). Yet, because rural schools serve low-population areas, educators typically occupy multiple roles and teach diverse content areas, rendering PD and integration efforts particularly impactful as teachers interface with a greater portion of local students (Autio & Deussen, 2017). Thus, despite reduced access to PD, this nature of the rural teaching experience may position teachers well to creatively and sustainably adopt new instructional approaches, such as integrating CT and community-based citizen science into their classrooms. Due to the strong connections to community and local environments that characterize rural places (Crumb et al., 2023), alongside accentuated restrictions to coding, robotics, and other digital opportunities, rural teachers' dual use of CT and community citizen science may illustrate their creative use possibilities in contexts often characterized as "under-resourced."

Recognizing these challenges and opportunities, our program, iWonder (iW), supported rural elementary- and middle-grade teachers to facilitate community-based citizen science experiences that use CT to explore local science questions. Here, we focus on teachers' self-efficacy (SE) in embedding CT competencies in student-led investigations. Our guiding research question is as follows: "How do rural elementary and middle school teachers characterize their CT SE as they implement CT in a student-led community-based citizen science investigation?"

Professional development in computational thinking and rural settings

Teaching computational thinking in elementary and middle school classrooms

CT is "the conceptual foundation required to solve problems effectively and efficiently" (Shute et al., 2017, p. 142). Since Wing (2006) popularized CT beyond computer science, "unplugged" CT has gained attention in classrooms, especially in elementary and middle schools, due to relatively low material, teacher training, and student preparation needs. These features make unplugged CT accessible for educators, such as those in rural schools, who have reduced access to technology tools or prefer to avoid computer-centric learning (Del Olmo-Muñoz et al., 2020; Delal & Oner, 2020; Yadav et al., 2016). The International Society for Technology in Education (ISTE, 2023) adopts this broader view in their CT Competencies, defining CT as a problem-solving process that includes the components in Table 1. While this broad view of CT makes space for integration across the curriculum (Boulden et al., 2018; Buffum et al., 2014; Wolz et al., 2010), Angeli et al. (2016) note that educators and educational leaders are challenged with both discerning what to teach and what knowledge teachers need to possess to integrate CT, particularly at elementary and

Table 1. Definition and core components of computational hinking defined by ISTE.

Computational Thinking Defined by ISTE
A problem-solving process that includes, but is not limited to, the following characteristics: • Formulating problems so technical tools can be used to solve them • Locally organizing and analyzing data • Representing data through abstractions, such as models and simulations • Automating solutions through algorithmic thinking (a series of ordered steps) • Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources • Generalizing and transferring this problem-solving process to a wide variety of problems
Core Components of CT
Decomposition: Breaking down a problem or system into smaller, manageable components
Abstraction: Reducing complexity by focusing on the main idea in a way that allows one to focus on the problem at hand; hiding details irrelevant to the question at hand
Algorithm design: Process of designing a step-by-step process, precise instructions or sequence to complete a task, especially for a computer
Gathering and Analyzing Data: Including collecting, storing, and representing information in a way that can be understood by a computer to help us find and recognize patterns , make predictions, and communicate important ideas

early middle school levels (i.e., K-6), where complex abstract thought is developmentally inaccessible.

Considering these challenges, recent research has explored teacher PD that may support elementary and middle school teachers to effectively integrate CT. Ketelhut et al. (2020) found that elementary teachers, through continuous and sustained PD, integrated CT with integrity and developed beliefs that CT could engage all learners. The positive effect of sustained CT PD is echoed in work with middle school educators (e.g., Biddy et al., 2021). Research has explored how CT PD supports elementary and middle school teachers’ awareness of CT’s relevance across STEM fields (Yadav et al., 2018), SE in using CT in classrooms (Avcı & Deniz, 2022; Çiftçi & Topçu, 2022; Rich et al., 2021), and CT integration across the curriculum (Yadav et al., 2018, 2019). Such work elevates interventions that define CT for teachers, illustrate its relevance to their classrooms, and provide tools and strategies to support their confidence in using CT.

Rural teacher professional development in citizen science

Rural education is often discussed in terms of what it lacks (i.e., online connectivity and access to PD sites) (Crumb et al., 2023), which has implications for teacher PD. Indeed, rural schools are constrained in supporting PD by features of rural spaces. Teachers may travel farther to access in-person sessions, they may have less funding to support their participation, and staffing and substitute coverage can be difficult to secure (Glover et al., 2016). However, there is a modest body of research on effective methods to support rural teachers that leverages the affordances of their settings and contexts rather than viewing them as a deficit. Such strategies include leveraging connections to place and community inherent in rural spaces (Howley & Howley, 2005); building opportunities for social connection (Skyhar, 2020); and developing learning communities based on trust, respect, and collegiality (Haar, 2003).

Given the strong connection to place and community inherent in rural education and rural educator PD, community-based citizen science is a promising context upon

which to support CT integration in rural schools. Christensen (2023) suggests that “learning about sustainable environmental solutions requires students to partake in computational thinking” (p. 26) due to the intersecting “spheres” of complex environmental solutions development. Environmental learning that includes CT can support thinking about these complex questions to account for this complex ecology of the issues Christensen (2023). While here we do not explore student outcomes directly, we view this context of the CT and citizen science field as an important justification for making sure teachers have support in simultaneously integrating these two approaches in their science teaching, especially at critical ages of science identity development (Archer et al., 2010).

Theoretical raming: teaching self-efficacy

We frame our study using teacher SE (Tschannen-Moran & Hoy, 2001, 2007), derived from Bandura (1982, 1997). While Bandura (1982, 1997) introduces four contributors to SE (i.e., personal mastery experiences, vicarious experiences, verbal persuasion, and emotive state), in exploring *teacher* SE, Tschannen-Moran and Hoy (2007) highlight the significance of a) verbal persuasion from peers, administrators, and individuals outside the school; and b) mastery experiences achieved through teaching endeavors. They further suggest influences of the teaching context on these SE calculations, such as teachers’ perceptions of the cultural, structural, and social elements that may facilitate or impede their exercising a new practice—a supposition supported by studies that specifically consider SE in CT (Saxena & Chiu, 2023) and socially conscious science learning (e.g., Borgerding & Dagistan, 2018; Kılınç et al., 2013).

Given the relationship between SE teaching capabilities and novel contexts, most teacher SE research focuses on preservice teachers (Menon et al., 2024). Yet, research-derived support recommendations proposed for *preservice* teachers are unlikely to directly apply to *experienced* educators. Indeed, Tschannen-Moran and Hoy (2007) indicate that novice teachers’ SE may be more prone than that of expert teachers to be influenced by verbal persuasion due to few accumulated mastery experiences. However, this characterization of “experienced” and “novice” is unique to each skill, such that, for instance, a teacher may be experienced in facilitating science learning in their classroom but a novice in using CT—a likely scenario given the relative recency of CT integration efforts. As experienced educators integrate new concepts, such as CT, into their classrooms, it is important to cultivate their SE with these pedagogical approaches to more reliably sustain their change in practice (Thornton et al., 2020), which likely entails verbal persuasion support in CT that leverages accumulated mastery experiences of science teaching.

Yet, little work has considered how teachers—particularly experienced teachers (Menon et al., 2024; Mintzes et al., 2013)—negotiate their CT teaching knowledge and performance. While some recent research (e.g., Rachmatullah & Weibe, 2023) considers CT teaching SE in “computationally rich” spaces, SE in unplugged environments that are more accessible to younger, rural learners is under-explored. Survey research exists (e.g., Rich et al., 2021; Saxena & Chiu, 2023) but stops short of exploring contextual attributes of schools and communities that contribute to teachers’ SE development—attributes that we believe to be important to recognize as assets in rural contexts where conversations about computational

learning often center on technological and/or professional deficits (e.g., Statti & Torres, 2020; Wargo et al., 2021).

Program & participants

For over 10 years, iW has supported rural elementary and middle school classrooms to study the local impacts of climate change. iW was co-designed with teachers, community members, and scientists from rural coastal Maine islands and communities and, beginning in 2019, included Mississippi and Alabama classrooms. iW program leaders recruited teachers using personal connections and through open calls in science and environmental teacher networks.

iW teachers engage in sustained PD throughout their participation (see Table 2). Throughout the experience, teachers and students access an online platform where they collaborate with each other, scientists, and other community experts, as they develop community-based science questions, refine data collection protocols, and visualize their data. Past projects have included investigations on the effect of weather on the timing of maple sap production, the effect of King Tides on coastal communities, and the presence of microplastics in drinking water. At the culmination of the year, each participating class develops an “Action Project” to share findings with their community or affect change based on their results.

Table 2. Supports for teachers in learning and implementing CT during iW participation.

Resource	Timing	Description
Summer Institutes	Summer 2021 & 2022	• Introduction to CT led by iW program leaders • Includes opportunities to collaborate with other teachers to identify opportunities for CT in curriculum and communities • iW scientists participate in the institute to begin developing relationships with the teachers
Collaborative iW website platform	Year-round	• Platform to facilitate student and teacher collaboration within and across classrooms participating in iW • Students and teachers create accounts so they can collaborate within their classroom and with other iW schools • Participating scientists create accounts and provide feedback and support for classrooms on developing their investigation questions and analysis plans
CT Bytes	Year-round	• Teacher resources designed by iW program leaders to be used in a classroom setting and fall into one (or more) of the “four buckets” of CT • Includes hands-on activities, links to resources and custom created slides for in-person or remote learning. • Available on the website to those with a teacher login
Professional development “pop-ups”	Year-round	• Synchronous meetings over Zoom, led by the iW program leader, to explain CT concepts, share CT resources, and strategize developing CT experience for students.
iW Staff Support	Year-round	• Individualized support from iW program staff that may include individual e-mail exchanges, Zoom troubleshooting sessions, or visits to classrooms to support investigations • iW staff help classrooms identify scientists with the background and expertise to support classroom investigations
iW Scientist Support	Year-round	• iW scientists support classroom investigations by providing advice on investigation protocols, data analysis, and general information about their career pathways virtually and in-person

Table 3. Example of CT components in an iW investigation on vernal pools.

iW Investigation Activity	CT Component	Description of Activity
Identifying a topic to investigate	Pattern recognition	Students walk around their schoolyard and write down a list of things they “notice” and “wonder” about. They come back to the classroom and group the questions into themes, discovering that several questions in the class fall into a pattern of relating to vernal pools.
Developing a SMART investigation question	Decomposition	Students use the SMART (specific, measurable, attainable, relevant, timely) question framework to create an investigable question. This framework breaks down the big task of creating an investigation into manageable components. They generate the question, “What are the dominant organisms found in the three vernal pools on our school’s property in the winter month of March and spring month of April?”
Developing a data collection strategy	Algorithm Design Abstraction	Students work with a local biologist to develop an organized, step-by-step, data collection protocol to identify micro- and macro-invertebrates in their school’s vernal pools. Together, they decide that they can use an existing vernal pool species identification resource rather than drawing each species and identifying it later, reducing complexity through abstraction
Field Data Collection	Gathering and Analyzing Data	Students use their protocol to collect data at their local vernal pools weekly for four weeks. Each week, they graph and analyze their data, looking for patterns about the species they see most in their vernal pools.

In 2021, iW introduced CT after co-developing with teachers modules that link CT with community-based citizen science. iW’s use of CT draws from the definition and core components identified by ISTE (2023; see Table 1), which aligns with existing research illustrating its applicability in unplugged contexts (e.g., Bower et al., 2017; Brackmann et al., 2017; Dong et al., 2019). Table 3 describes how one classroom applied CT to study vernal pools.

Researcher positionality

Heidi is a white woman and first-generation college graduate who grew up in the rural U.S. south, where she taught high school science. In many of her encounters with citizen science, she was skeptical of its appropriateness in classrooms because she observed that it was often rote and infrequently translated to learning. She was excited by the prospect that CT could provide a structure for citizen science learning experiences that would lead to more engaged thinking and student leadership in learning, but she did not have much experience with CT. Thus, she recognized early in the inquiry that she needed to rely on the teachers’ articulations of CT and their experiences in learning about CT without much personal experience to draw upon. She approached interviews with legitimate curiosity in understanding the experience of learning CT.

Alex is a white woman and first-generation college graduate who grew up in suburban Massachusetts and currently lives in rural Maine. She worked for seven years in a marine science education nonprofit where she collaborated with public middle school alternative education programs instructing science through place-based citizen science. As such, she was aware of the power of these types of projects in which students take leadership and ownership of their learning, especially students who may have difficulties in traditional classroom structures. However, the CT integration into citizen science was new, and she was hesitant about layering it onto a full plate for teachers. She often probed throughout the inquiry to understand how this integration was actualized in projects. She was interested in learning

Table 4. Timeline of data collection events for all iW teachers.

Dates	Data Collection	Purpose of Data
July 2021	Early-Year Surveys	● Assess knowledge, values, and confidence in using CT in the classroom
August–September 2021	Early-Year Interviews	● Gauge participation in available supports for using iW ● Learn about prior experience with CT ● Get feedback on available supports from the iW team and anticipated challenges
February–March 2022	Mid-Year Interviews	● Assess on-going needs and perceptions of CT ● Inform the development of additional professional learning resources
May–June 2022	End-of-Year Interviews	● Check in on how the first year of using CT in the iW project played out for the teacher ● Inquire about areas where more supports were needed
May–June 2022 September 2022	End-of-Year Surveys Early-Year Interviews	● Identical to Early-Year Surveys to allow comparison ● Learn about prior experience with CT ● Get feedback on available supports from the iW team and anticipated challenges
September–October 2022	Early-Year Surveys	● Assess knowledge, values, and confidence in using CT in the classroom ● Gain information for informing PD supports throughout school year

more about the varied approaches that the teachers had to CT, outside of integrating it into the data analysis portion of investigations, where it seemed to be the clearest fit.

Approach to inquiry²

Our research is a multiple case study with three case teachers. This design supports our purpose in organizing our findings to illustrate the contextual influences on teachers’ experiences and in accounting for those contexts as we compare and contrast their relationship to the phenomenon (Merriam, 1988). We also considered their experiences as particular to unique rural contexts and designed our methods to be responsive to these variations. Our approach is *constructivist* (Lincoln & Guba, 1985) in that it is guided by a belief that realities as constructed by those who live them are what matters in understanding phenomena.

All iW teachers responded to surveys and interviews throughout their participation (Table 4), which informed program design and development. We use these data to help contextualize our participants’ experiences in the iW program and to personalize data collection events that are specific to this study. This work is approved by Salus IRB #20104. We obtained informed written consent from all participants included in the study prior to any data collection.

Interview content and structure

We interviewed case teachers to detail their experiences in enacting the CT component of iW. We leveraged phenomenological interview techniques in our design of interviews to elicit recollections of lived experiences in rich detail, including what was observed, thought, and felt during the experience (van Manen, 2014). As such, we structured our first interview

²We recognize that data collection and analysis is a complex process that engages many more components than can be reported in a journal article. We rely on the APA journal article reporting standards for qualitative inquiry (Levitt et al., 2018) to select the content of this section.

to build on responses to general data collection events (see [Table 4](#)), including questions about how the teachers first encountered the term CT in the training, how they recalled enacting CT in their investigations, and the outcomes they observed in students. The interview probes derived from research on preservice teacher SE (Settlage et al., 2009), and surveys in teacher SE (Smolleck et al., 2006, cited in; Mintzes et al., 2013) and in teaching CT (Boulden et al., 2021).

We noticed that across these initial interviews, teachers spoke similarly about their motivation to participate in the program, the instructional strategies they adopted and adapted, and their role in yielding desired student outcomes. Recognizing this and the fact of the teachers' history discussing with one another their growth in the program, we held the second interview as a participatory meaning-making interview to encourage teachers to build an understanding of their thoughts and actions—and the SE that undergirded them—through conversation with peers with whom they could relate and trust to understand their experiences (Cornwall & Jewkes, 1995). While SE is a personal experience, creating this context supported our methodological integrity (Levitt et al., 2018) through its likelihood of generating discussions among participating case teachers, which our histories with them had suggested, would align with our research goals. We returned to the teachers individually for a final interview, here building more personally on the ideas that were generated by the group conversation.

Data analysis & theme development

We began emergent coding (Miles et al., 2019) following the group interview. As our purpose was to constructively explore how teachers experienced implementing CT pedagogies during a student-led investigation, emergent coding allowed us to ground meaning-making in participants' language (Charmaz, 2017). We used *in vivo* coding and gerund coding to reflect our participants' phrasing and frequent reference to actions as they talked about their teaching (Miles et al., 2019). Recognizing the unique positions we each had related to the inquiry, we did not seek coding consensus (O'Connor & Joffe, 2020). Rather, we defined codes, independently applied codes, and discussed differences in coding to stimulate conversations about the data and deepen our engagement with it. Following this process, we collaborated to carry out axial coding (Miles et al., 2019) to identify connections relevant to our research purpose. The axial codes formed our first draft themes, which we further refined by drafting themes in reflective journals and iterative meaning-making conversations with iW program leaders.

Selection of case teachers

Multiple case study research facilitates understanding contextual contributors to experiences of a phenomenon through extensive data collection of individual units (Stake, 2013) that share key characteristics while differing in relevant comparative features (Ragin, 1992). Case teachers shared (1) participation in the iW program and (2) five or more years of teaching experience in Maine. We selected experienced teachers to observe the unique SE experiences of CT in the community-based citizen science context, which could become confounded in novice teachers who would have broader SE demands. We selected educators in Maine due to our own familiarity with these communities, its educational system, and its educators. Heidi was new to the iW team and did not know the teachers. Alex worked with the iW program for seven years. She interacted with two case teachers through

associated work in the environmental education community in Maine and knew one of the participants personally through her prior employment.

Diversity across cases is critical to explore how contextual differences relate to variations of the phenomena of study (in our case, SE) to illustrate and inform theoretical ideas. We diversified (1) the number of years of participation in iW, and (2) the context of their rural classroom. The former was informed by conversations with iW program leaders who expressed that teachers who were new to iW may see the CT component as more integral to the program, while those who are more seasoned may have approached it as more of an add-on. The latter derived from literature on the diversity of rural school experiences, which are often poorly reflected in existing research that considers rurality a monolith. Descriptions of the case teachers are provided in Figures 1–3 and demonstrate the diversity of their experiences in teaching and their initial views of and confidence in instructing CT from their pre-survey responses.

Outcomes of inquiry

We translated our refined axial codes to four themes, summarized in Table 5, which reflect how we saw case teachers express their SE with CT teaching in the context of a student-led

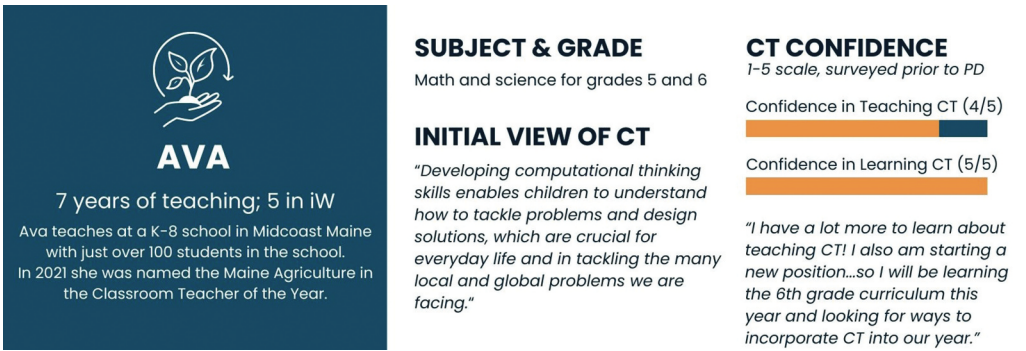


Figure 1. Prior to the program, Ava (pseudonum) viewed CT as an important tool for her students and expressed confidence in learning CT.

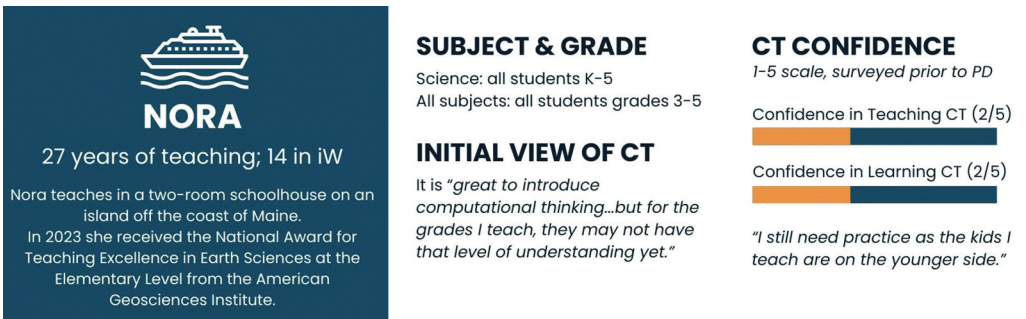


Figure 2. Nora (pseudonym) was our most experienced participating teacher. She expressed skepticism of using CT with younger students.

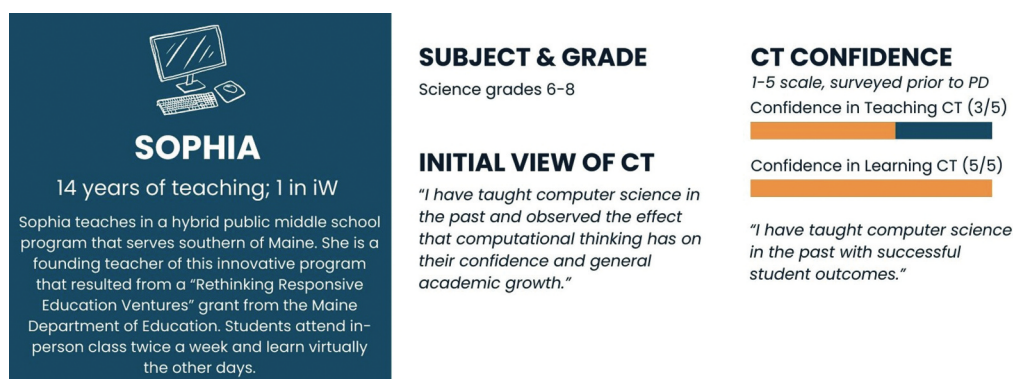


Figure 3. Sophia (pseudonym) was unique among our cases by teaching in a hybrid school. Prior to the PD, she indicated some experience in CT.

Table 5. Summary of themes.

Theme	Theme Summary	Associated Codes (sample)
Teacher as Learner	Teachers see themselves as constantly learning, including learning alongside students as they try new pedagogies, like CT.	“Am I qualified?” “The more I do it, the better I get”
Defining and Monitoring Student Outcomes	Teachers define what student outcomes are valid measures of success of their pedagogical experiments and evaluate their teaching success according to those metrics.	Seeing evidence of success (or not) in students “The kids can do it.”
Perceived Broader Value of the Work	Teachers situate their new pedagogical attempts within broader meaning of what they feel is important for their students beyond the classroom.	Seeing CT as interesting, exciting, or fun Seeing CT in daily life/the real world
Social Engagement with Other Teachers	Teachers derive support for their new pedagogical attempts through community with teachers who share the experience.	Hearing encouragement from others Learning or getting resources from other teachers

community-based citizen science investigation. We organize our findings by discussing each theme for each case teacher.

Nora

Teacher as learner

Nora noted, “I am a learner; I like to learn. And that’s kind of how I’ve always taught. And I actually thought that’s how everybody should teach” [I3].³ Her view is reinforced by a reciprocating school culture—likely a mutual reinforcement given Nora’s veteran status. She reflected, “My kids know that I’m learning with them . . . And that’s how we roll at my school.” While Nora embraced this teacher-as-learner role, and although she had been involved in iW longer than any other teacher in the program, she expressed difficulties in adapting to the new CT component. She rated her confidence in CT lower than either Ava

³We use brackets to indicate the data source of each quote. I1 and I3 refer to the first and third interviews, and GI refers to the second interview, which was a group interview.

or Sophia prior to the iW training that introduced CT. In this context, she leaned on a culture of honesty and transparency with her students to work through the challenge the new practice created for her personally.

I was very honest with the kids that . . . “We’re going to learn this together and I might not have exactly, but this is we’re gonna try” . . . It was a little bit scary and stressful because I wasn’t sure if I got it exactly right. But I think that one of the things that we’re good at [as teachers] is being honest with the kids that we might not have it exactly right. [GI]

This process of learning alongside her students, according to Nora, added to the richness of her teaching experience and the learning process of her students. She appreciated that, in her classroom, “I don’t have to be the expert,” and she can ask her students “What do you think?” She acknowledged “I know that sounds like I’m trying to teach them and trying to make them be better thinkers, which, yes, I am. But I genuinely want to know, because I’m not sure.” [I3].

Defining and monitoring student outcomes

While Nora is enthusiastic to learn alongside her students when she implements new teaching strategies, her status as a veteran teacher predisposes her to be skeptical of “buzzwords” in educational movements, like CT. She reflected that she’s “not blowing it off. It’s just that I don’t have the buy-in like some people” [I3]. Nora characterized the elements of CT as somewhat tangential to the real mission she sees in teaching, which is encouraging students to think with curiosity about local phenomena. These “buzzword” concepts contain different tools that Nora finds useful, but she is less prone to excitedly embrace new concepts largely because she does not see them as new in the larger context of what constitutes effective teaching.

In reflecting on two years of CT integration, Nora discussed an evolution of her CT teaching SE, which she paralleled with her students’ growing confidence. She noted that “at first it was very abstract to me,” but “as I’m getting more confident with it, I’m able to bring it up a little bit more. And the kids are getting more confident with it” [GI]. Part of what characterized this evolution was Nora’s growing professional agency in deciding whether and how to integrate these new ideas into her teaching, balancing more decontextualized guidance from the PD providers while evaluating what is most appropriate for her students. For instance, she discussed grappling with how often and under what circumstances to name CT activities for her students, saying that they use CT every day, but she needs to be “better about” calling attention to its use in the classroom and naming specific employment of CT concepts, such as pattern recognition. But, she noted that “I’m not sure if I need to shove it down their throat either” [GI].

In this way, Nora indicated a shift, where her focus moved from a learning goal that she was trying to achieve as a *student* of CT—differentiating the four pillars of CT—to a learning goal she *had for her students*—using CT skills non-discretely to approach a community-based citizen science investigation. Nora addressed some of this negotiation by adapting materials and deciding how to present CT to her students based on where she perceived the most value to exist for them. When broadly operationalizing CT, Nora believed her students could use CT and described how they surprised her by demonstrating that they are “better at” CT than her, particularly those students whom she taught for consecutive years. Here, Nora again referred not to defining CT or its components but to

her larger goal of using tools to understand students' local world and rural coastal setting, which she uses as a central context for instruction.

Perceived broader value of the work

Nora's biggest motivation to continue learning and bringing new experiences and concepts to her students, such as CT, derived from her desire to ensure that the students in her rural island community had access to high-quality opportunities and knowledge, especially when they transition off their small island for high school. She reflected that when she has an opportunity to learn a new teaching strategy, "I feel like it's important for me to learn it. Because I want to make sure that my kids are on a level playing field when they go to town." [I3]

Nora suggested that CT is relevant to her rural students because living in remote places naturally cultivates skills in creative problem-solving because "you're never in a position where you cannot help yourself out" [GI]. She articulated that because students come to her science classroom with some lived experience in exercising these skills, her role as a teacher is to nurture those skills and apply them to science learning. Thus, she does not see her role to be teaching CT to students who already have some of these skills but rather in honing those existing skills while also keeping in mind the necessary preparation for future learning where explicit instruction on the academic use of CT will, Nora perceives, be more necessary for her students' success.

Social engagement with other teachers

As one of the only teachers in a one-room rural schoolhouse, Nora found the interactions she had with teachers in the iW learning community to be critical in her developing CT knowledge, noting that she perceived that her "science teacher colleagues are all on [iW] because I don't have other teachers to talk to otherwise" [I3]. Even though Nora was the most experienced teacher in the program, she felt that she continued to develop her teaching and CT understanding by interacting with other teachers, as well as deriving support and encouragement from them. She tied her comfort in this vulnerability as connected with her view of the other participating teachers as colleagues, recalling, "They are who I talked to about different things, and . . . if I have a question saying, 'Okay, I'm not getting this, how do I get that?'" [I1]. Even while Nora felt that some of the suggestions shared in PD events for integrating CT were beyond the scope of her classroom grade level, she still found value in the conversations for her own growth and development of CT knowledge and skills. She tied this value with her own understanding of CT, which could translate to the experiences she presented to her students because "I think the more that I use it, the better I'll be using it in the classroom" [I3].

While Nora drew support from the iW teachers across other rural regions of the country, she acknowledged that her community and school culture also allowed her to teach in this way and placed trust in her as a professional to do her job well. She acknowledged that her school administrators "allow me to go off and teach the way I want to. And actually, it means the way the kids want to." Then, with this affordance of autonomy "we're able to bring it back in and then afterward, I go through the standards and make sure that we hit everything." [I1]. Thus, Nora drew differentiated support from two sources—support for "how to do" CT from iW partners and support to experiment with her teaching as she draws

from that collegial support in the form of administrative and community trust and accessibility to resources from her school.

Ava

Teacher as learner

Ava also embraced her position as both teacher and learner, which was especially salient in the earliest stages of adopting the CT component of iW. She reflected that, though she didn't feel particularly strong about CT, she reminded herself, "Oh, this is great. I'm getting to learn with [my students]. And then once we both learn, I'm gonna feel a lot better moving forward" [I3]. Ava also acknowledged that feeling more comfortable and capable in CT influenced her excitement, reflecting that when she first began the CT component of iW "I didn't feel that confident with it. So that might have limited some of the enthusiasm." She discussed that this reciprocity between confidence and enthusiasm may relate to her personal tendencies because "being modest just naturally kind of comes because I don't like getting credit for things" [I3]. This acceptance of herself as a learner is evident in the way Ava speaks un-self consciously about areas where she notices opportunities for improving her CT teaching. For instance, she expressed that "sometimes [my students] want a little bit more from me in terms of examples," specifically with the skill of pattern recognition, "so that's something I'm working on" [I3].

While here Ava reflected on an area of her teaching that needs growth, she acknowledged that there are instances when her status as "learner" and "teacher" require her—in the moment—to pause and remind herself of the value of this dual role to the learning experiences of her classroom, evoking that "faith" in herself to provide a valuable learning experience.

There's definitely moments, certain questions that I might sometimes be caught [thinking] "I really feel like I should know this," and I think that in my head for a second, then I have to tell myself in my head, "That's okay. Here's a teaching moment" . . . Other times, it's something that I'm like, "Oh, why *would* I know this?" [I3, emphasis in original]

While Ava acknowledged the impracticality of having all the answers for her students, she also spoke about embracing opportunities to develop confidence in CT teaching, which she felt was important not only for her fluency in teaching but also for the enthusiasm she demonstrated in class. For instance, many teachers in iW spoke about feeling intimidated by a graphing software program, Tuva, that the PD providers shared during the summer session. Ava reflected that she was "nervous about it" and "definitely had, you know, a little bit of being just like, 'Oh, I got to learn how to do this'" [I1]. This determination manifested when she volunteered to pilot using Tuva with her students. Ava recalled of this experience

It was allowing me to do the right steps sort of in the right order . . . Because a lot of it really is confusing to kids, if they don't have a teacher to help guide certain aspects about it. And so doing that allowed me to see, what should I let the kids explore on their own? And what are some parts of it that really, a teacher could help? [I1]

Defining and monitoring student outcomes

The outcomes to which Ava attended to monitor her teaching effectiveness concerned student ownership of learning experiences. So, rather than feeling like she needed to understand CT perfectly to be an effective teacher, she expressed that student freedom to lead their learning enables CT learning to take place, and for her to feel like she is effectively teaching CT. She reflected that when she made space for her students to “use their critical thinking skills to try and figure out how to do it “CT was “really starting to click [for me] that, ‘Oh, I’m [teaching] computational thinking . . . enabling them to take ownership of how to do an investigation”” [I1].

While Ava acknowledged the value of student leadership, she also recognized her responsibility to scaffold student thinking to align with content learning goals by “letting them ask questions about all the problems that we’re learning about.” Ava reflected that “leading them to these problems” is “inviting” them to CT by “letting them take the direction of the problem.” [GI]. She attributed this perspective to her university training and that her school community supports her in establishing a classroom environment conducive to students learning from one another about community-relevant topics. She appreciated that teachers at her school “try to have as much discussion with the kids as possible in instilling critical thinking and looking at both sides of something,” which she believed “really helps” [I3] with supporting students to apply CT.

Perceived broader value of the work

While Ava talked about student outcomes that are tied to CT skills and the standards, she also made clear that she is intentional about broader life skills that she feels students should adopt, especially “to learn by seeing an adult be like ‘I’m not sure. That’s a great question”” [I3]. As with the observations of student CT learning that Ava attributed to discursive patterns and student leadership norms she established, Ava framed her status as a learner of CT as an asset. She acknowledged “It can be hard if they ask something and you don’t know” but that it is valuable, in these cases, to “try and think of it as an important learning opportunity for them to also see that adults don’t know everything, and we’re all learning and you’re going to be learning the rest of your life,” adding “it’s also a good lesson in modesty for the kids.” [I3]. This perspective illustrates the perceived alignment she sees between CT, the learning objectives she has for her students, and the learning objectives she has for herself as a teacher.

I like how [CT] gives them a chance to slow down and go step-by-step with things, and the critical thinking skills that are involved with it. That to me is hugely important obviously for the rest of their life if they can utilize those skills to be thinking about this problem of what’s important, what’s not important, what am I doing first? And next? [GI]

Social engagement with other teachers

Ava spoke of interactions with other teachers as formative experiences to her developing SE in teaching CT in two ways: 1) hearing encouragement from other teachers that reassured her that efforts aligned with her definitions of success and 2) developing and piloting resources to share with other teachers.

When Ava heard feedback from others suggesting she had already implemented some aspects of CT in her classroom, these affirmations made her feel more capable of teaching

using CT integration. While she recalled this support from iW leaders, she reflected particularly on the importance of reassurance she received from other iW *teachers*. She recalled that in a summer session, “a couple of the iW teachers were talking about using graphs and tying that in with [CT]. And that made me realize, “Oh, yeah, I do a very similar thing.” When she shared an activity she did with her students as part of the conversation, she recalled her peers suggesting that ““Well, I mean, that’s doing the same thing’...[and] I was like, “Oh, okay. That’s right.”” [I3]. Here, discussing CT’s classroom applications with peers created space for her to share activities she did in the classroom that she could relate to her peers’ examples. This contribution, in turn, garnered recognition from her peers as aligned with the CT teaching objectives.

While in this instance, Ava discussed sharing moments of reassurance with peers, she also spoke to the value of collective uncertainty of “seeing the other teachers feeling the same way” that “I’m not sure about this yet” showed Ava that “we were all sort of in it together” [I3]. This, combined with a feeling of “nurturing” [I3] from the iW staff, contributed to Ava’s confidence moving forward, including being an early adopter of strategies that supported CT instruction, as noted above in the case of piloting the Tuva software with her students.

Sophia

Teacher as learner

As the newest iW teacher of our cases, Sophia recalled wondering early in her iW experience, “Am I qualified to be part of this program?.” She shared that, when she started the program, “my initial thought was, ‘Computational thinking, oh, my gosh, this is above my head.’” [I3]. This view affected the excitement she typically feels in taking on a new challenge in her teaching, as she admitted “I was fearful of it, to be honest. [I thought] ‘Oh my gosh, I’m not smart enough for that one’” [GI].

Sophia specifically referred to CT as the aspect of iW that she was “fearful of,” but she acknowledged that her foray into teaching with CT coincided with other significant changes for her as an educator. The year she began, iW was also her first year teaching in a new virtual middle school that was designed to meet the needs of students with learning differences or who struggled to transition back to in-person school after the COVID-19 school closures. However, Sophia found community-based citizen science to be a natural fit with the project-based model that her school supports and frequently mentioned the importance of learning alongside her students, particularly in how new methods of learning introduced excitement into the classroom.

Despite Sophia’s enthusiasm for co-learning with students, she acknowledged the “fine line” that she must walk to ensure that students still respect her authority as an educator “between them appreciating and really becoming involved in the process because they know we’re in it together” and “them kind of trying to take control and losing respect for me as an educator because they think they know more, especially in the middle school.” [I3]. This tension may be uniquely present for Sophia among iW teachers because she works with older students in upper elementary and early middle grades, something she alludes to having less confidence with when she described how she had to relearn content for upper-grade subjects, specifically math.

Defining and monitoring student outcomes

Sophia reflected on the opportunities of CT, specifically in light of the unique talents and difficulties that come with being a learner with ADHD, like herself and many of her students who are drawn to virtual, hybrid schooling. Sophia saw success when her students used CT tools to reduce barriers they typically face when encountering complex problems, like in community-based citizen science. She reflected that CT “really gives them a tool to feel successful and to try” because, for learners “with ADHD brains, it’s hard for us to break things down” [I3].

While noting this value of CT, she also acknowledged that CT can be challenging because it requires making thought processes visible, which she says is especially difficult for her students who “just know” the answers. She explained that for these students “to actually show me the process, that is really challenging and frustrating . . . because they’ve done it in their mind. And they just know it, and they can’t articulate it any other way” [I1].

Sophia sees both the challenge and opportunity in CT with her population of students, where it can help students to “break things down” but also introduces frustration because of difficulties in articulating problem-solving methods that require step-by-step thinking. In this way, she positions her role as an educator using CT uniquely among our program teachers.

Perceived broader value of the work

As suggested by the student outcomes that Sophia attends to, she perceives CT to be valuable both as a life skill for problem-solving and as a fun and exciting game that engages students and has social-emotional benefits. She described CT as supporting her personally and professionally as a tool to work through problems as well as for learners diagnosed with ADHD and whose learning approaches are not readily accommodated in most schooling contexts. She believes that CT “offers them that consistent framework that helps them to be effective in really anything they do, whether it’s in real life, or whether it’s a school-based task” [GI]. She noticed the most value in CT in the ways that its practices can frame student interactions and mindful approaches to questions that arise, which in turn makes learning experiences more enjoyable. She reflected that, based on this, it is important to express CT as an “avenue for critical thinking, for collaboration, for deeper learning, and reduced stress. Because any student learns better when they’re having fun, and when they’re not stressed out.” [I3].

Social engagement with other teachers

Sophia described how her social interaction with the other iW teachers and staff was critical in helping her move past her initial hesitancy and discomfort with CT. She recalled a transformational moment during the summer institute in which she interacted with an iW teacher in a Zoom breakout room to discuss how they understood CT and its fit with their teaching:

We were able to sort of problem-solve through things. And it was just a very safe environment to really be vulnerable and be like, “Ah, I don’t know if I had this.” And I just walked away from that whole experience realizing, “Oh, I’m not off the mark. This is what I think it is. And I can really use this.” [I1]

In the group interview, she elaborated

Once I stopped trying to pretend like I knew it, and I just was honest, and like, “Okay, I hope they don’t kick me out, but look, I mean, I’m having trouble”. . . And I think once a person gets to that point, I know for me, once I was real and open about my struggles or uncertainty, then everything works out. Because really, we’re in a supportive profession.

Since this experience, Sophia’s confidence in CT has developed to the point where she introduced CT to other teachers in her school, and she has helped embed it as a component across all subjects. She described the value of the virtual school structure of collaboration and how that contributes to teachers having a consistent message about CT, who “reference it now too” when they approach problems thinking, “Okay, so we’re breaking this down into smaller parts, right? Just like [Sophia] taught us with computational thinking.” [I1].

Discussion: cross case analysis

Tschannen-Moran and Hoy (2007) indicate that verbal persuasion and mastery experiences influence teacher SE, though their relative contributions vary according to teacher experience. Our case teachers are “experienced” as rural science teachers and “novices” in CT, allowing us to explore how teaching mastery experiences intersect with verbal persuasion of their CT capabilities to influence overall CT teaching SE.

Teachers’ definition of “good teaching” supports SE in implementing the unknown

Teachers positioned themselves as learners alongside their students, which, in turn, framed their developing knowledge of CT as an asset to their teaching. They valued nurturing their own and their students’ curiosity and embracing novel approaches that were introduced by their students rather than explaining CT flawlessly. This finding clarifies disparate research that, on one hand, indicates no significant correlation between science teacher SE beliefs and content knowledge (Menon & Sadler, 2016) and, on the other, suggests an association between content knowledge and SE (Kaya et al., 2021). Case teachers’ SE in CT teaching was not related to their content delivery or even facilitation of scientific practices, but in cultivating a community of curiosity and excitement. Indeed, when teachers spoke about CT integration as difficult, it was usually in reference to their own challenges in learning CT rather than sharing CT with their students, although they grappled with adapting the content for grade-level appropriateness and were mindful of the perceived capability of their students to learn different CT concepts.

Kaya et al. (2021) found that teachers felt more capable using teacher-centered, guided inquiry than student-centered, open-inquiry instruction. Conversely, participating teachers framed student-led inquiry as a feature of the community-based citizen science program that *reduced* the efficacy burden of providing students with direct answers to questions about CT. Thus, they accumulated mastery experiences by assessing student ownership and engagement, which aligned with previous teaching successes. Yet, they also spoke reflectively about asking themselves what they “should know” to support students in ways that minimized student frustration and sought development experiences with iW staff that built mastery of those activities. Yet, Sophia’s experience illustrates how the challenge of adopting

CT can be heightened when it intersects with demands to acquire other forms of content knowledge.

Contextual contributors to SE evaluations

When learners engage in specific performance tasks, those tasks take place in contexts with characteristics that may increase or decrease the likelihood of success (Bandura, 1997). For instance, a teacher attempting CT integration may have their success stymied by administrative oversight that strictly regulates pedagogy and curriculum. While Tschannen-Moran and Hoy (2007) found school setting “unrelated” to SE beliefs, they characterized school setting narrowly, only differentiating urban, suburban, and rural. In contrast, our case teachers’ evolving comfort in integrating CT in a community-based citizen science program highlighted assets of these settings—a departure from the typical deficit-based framing of rural schooling (Crumb et al., 2023). Case teachers noted that community and administrative trust—and the coincidental freedom it afforded them to make decisions about their pedagogical practices—facilitated their embrace of new challenges. These features of their work environment allowed them to take risks that made possible the mastery experiences that would contribute to their growing SE within a context of psychological safety that resonates with the value Bandura (1982) describes of emotive states on SE. This agency, in turn, set the conditions upon which mastery experiences could be built due to a culture of experimentation and “learning with the kids.”

This freedom may have been further afforded by the small and isolated nature of their rural schools, where teachers—to various extents—had influence over the science teaching that occurred across all grade levels in their school and where “real-world” learning is valued. Teachers all had a history of success with place-based education within their local communities, which translated to administrative and community trust for expanding their classrooms beyond the four walls. Layering in CT to these projects was, therefore, just another innovation that they introduced to support their students’ learning. However, they also spoke about unique challenges that are associated with rural teaching; all taught multiple grade levels simultaneously and thus needed to differentiate experiences among the grade levels. As described by Skyhar (2020), people are both a great resource and a limiting factor in rural communities, as heavy workloads and multiple responsibilities must be distributed amongst a few individuals.

Social encouragement raises SE in early skill development

Setbacks experienced early in skill development can place overall progress on a more precarious footing because the learner has fewer mastery experiences in which to contextualize their negative experiences. The SE consequences can be compounded when such hitches naturally coincide with emotive states of fear and anxiety, especially when learners attribute these feelings of negative arousal to personal inadequacies (Bandura, 1997). Our participating teachers expressed these kinds of self-doubt in the early days of the iW program when CT was introduced, questioning if they were “right” for the program as they struggled to understand CT.

As suggested by Tschannen-Moran and Hoy (2007), verbal persuasion has pronounced value at these stages in the absence of mastery. Indeed, our case teachers valued hearing

from program leaders and peers that their current teaching practices aligned with CT teaching. These verbal reassurances retrospectively created mastery experiences, which opened opportunities for teachers to consider how to draw upon familiar community-based science teaching practices to apply to the novel context of CT teaching. The availability of this feedback appeared to be especially consequential in our rural case teachers, who expressed that they otherwise did not have peer science teachers in their small schools with whom to discuss CT integration. The iW program fostered these important connections and conversations between rural teachers while also strategizing to meet with teachers directly as needed (see [Table 2](#)).

Conclusions and implications

Prior work on citizen science implementation indicates that the student work often ends with data collection (Roche et al., 2020). In such cases, educators' SE demands are reduced as the difficult thought work inherent in making sense of data, applying it to a community problem, and sharing that thinking with others are eliminated from the process. However, this approach minimizes the growth and agency of the learners in developing scientific expertise, curiosity, and a sense of ownership. Infusing CT practices in the process may draw attention to the full life cycle of data engagement. Our participating teachers' value of "learning alongside my students"—and its associated redefining of mastery experiences that can be acquired during a community-based citizen science investigation that infuses CT—points to possible approaches to support teachers as they adopt novel approaches. We found that these perspectives supported CT teaching SE because they aligned with teachers' existing classroom culture of collaboration, excitement, and curiosity. Rural contextual factors, such as administrative support and community value for place-based education, further supported SE. This suggests that aligning PD with the affordances of rural settings can be effective for teacher SE in new content areas.

The iW PD strategy supported developing teacher SE by prioritizing social connections for rural educators. Teachers and support staff comprised a learning community that provided support and social encouragement, which enabled teachers to persist through difficulties. iW program leaders facilitated these connections intentionally by providing synchronous and asynchronous space for regular discussion, collaboration, and support. We found this feature to be critically important for rural teachers—especially in early adoption—and believe that such a community bedrock should be a component of any PD for rural educators.

Limitations and future research

We explored CT integration as part of an established and trusted iW program. As such, iW developers had already considered teacher supports, through years of feedback, that may be required for a community-based citizen science program. Programs that *begin* with CT integrated into such investigations may pose additional SE challenges to teachers as the community-based science components are established. Further, our research did not differentiate the relative influences of school support systems upon which participating teachers relied. Future work that more directly studies administrative cultures in rural settings that expert teachers leverage to sustain novel teaching approaches would provide more valid recommendations on *specific*

necessary school support systems. Finally, our discussion of learners with ADHD is limited to one teacher's reflections and should not be assumed to extend to other learning differences.

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