Teaching Computational Thinking in Grade School Requires “Just Right” Individual Teacher Support

Abstract

In-service teachers implementing a science, technology, engineering, and math (STEM) curriculum centered on computational thinking (CT) work with unique content and pedagogical experiences. Understanding how curriculum design and teacher professional development affect curriculum implementation can help researchers understand the critical aspects of supporting the teacher in "just right" ways to learn and teach an embedded CT curriculum. We qualitatively analyzed 22 teachers' discourse through a case study approach. We identified how CT is afforded and constrained through curriculum design and teacher professional development support. Teachers expressed that the supports that were critical to their confidence and perceived ability to teach CT were a) a program that provides "just right" support, b) a program that provides options and individualization, c) an internal personal identity that embraces continual innovation and learning, and d) an educational system that is encouraging and supportive of the effort and creativity it requires to implement innovative and intensive embedded CT programs. These findings can inform how to support teachers to integrate CT within existing STEM curricula as a core scientific and mathematical practice and to foster student interest in computer science.

Teaching Computational Thinking in Grade School Requires "Just Right" Individual Teacher Support

This study investigated how elementary and middle school in-service teachers expressed how they felt their learning and teaching about computational thinking (CT) could be efficaciously supported and encouraged during an ongoing professional development (PD) and curriculum integration program within a citizen science project.

Rabiee and Tjoa (2017) explain that CT is a term coined by Jeanette Wing and is simply a specific method of thinking. CT is a fundamental tool for finding solutions in a broad scope of disciplines and real-world situations (Rabiee & Tjoa, 2017). It has been defined as "the process of recognizing aspects of computation in the world that surrounds us and applying tools and techniques from Computer Science. . ." (The Royal Society, 2012, p. 29). Weintrop et al. (2016)'s definition of CT unpacks this "method of thinking" and elaborates that CT consists of four main categories: data practices, modeling and simulation practices, computational problem-solving practices, and systems thinking practices. CT, therefore, requires skills and universal competence that every child should possess (Bower et al., 2017). In addition to being a broadly applicable problem-solving tool, CT is an important foundational skill set and allows young children to develop an interest in computer science (Ketelhut et al., 2020).

We felt it was important to utilize this research opportunity to underscore the importance of CT because "science and mathematics are becoming computational endeavors" (Weintrop et al., 2016, p. 127). The Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) includes CT as a core scientific practice, thus highlighting its importance (Weintrop et al., 2016) and potential to be part of science education (Hestness et al., 2018). Additionally, there is an overlap in CT practices with the Common Core State Standards Initiative in mathematics (Rich et al. 2019). Accordingly, elementary and middle school teachers need to understand CT, especially embedded CT, and how to integrate it into their practice, something that has thus far been a challenge (Killen et al., 2020). This research highlights important in-service teacher discourse to leverage their expressions of incorporating CT into core subjects as one way of bringing early computer science (CS) education into school (Rich et al., 2020). We wanted to understand, from the teachers themselves, how curriculum and PD can be considered together to help teachers understand and implement embedded CT more effectively. Minimal research has explored how teachers translate their knowledge of CT into practice to create opportunities for students to engage in CT during math and science (Rich et al., 2020).

Additionally, there is little research on how CT could be embedded within elementary and middle school subjects (Yadav et al., 2018). Weintrop et al. (2016) suggest embedding CT in science, technology, engineering, and math (STEM) contexts across the early grades and determining how the integration of CT is supported through effective PD. If CT integration requires effective PD (Hestness et al., 2018), then what do teachers say are ways that help them to understand and operationalize CT across subject areas?

Teacher Identity

We focus on professional teacher identity (Avraamidou, 2018) because if teachers do not feel like they have the professional identity to teach these new-to-them concepts regarding CT, their teaching practice may be challenged in ways that ultimately cause students to have negative experiences in learning the concept (Israel et al., 2015). Additionally, there is no widespread agreement about strategies for teaching and assessing the level of CT development in students (Brennan & Resnick, 2012). Teachers are the agents of these desired changes in the classroom (Leander & Osborne, 2008). Therefore, it is important to deeply describe the most critical influence on the students' learning, their classroom teacher, by centering their expressions and discourse (Kelly & Green, 2018).

A teacher's identity is positional and personal to each teacher (Avraamidou, 2014). Further, professional identity is constructed through their professionally-related lived experiences within the contexts in which teachers work (Avraamidou, 2018). For example, the school system is one part of the context in which they work—they must contend with the policies, culture, and requirements of that school system (Lasky, 2005; Shilling, 1992). Teachers, therefore, express their actions through dynamic processes and the interplay between multiple discourses, such as the "proper," "good," and "science or math" teacher, and the cultural norms, resources, and subject positions available to them (Hwang, 2009, p. 697).

Teachers navigate complex contexts, including administration, students, student learning, and current sociocultural and sociohistorical contexts (Lemke, 2001). Because of their role at the center of student learning and reform, teachers—and thus their expressions of agency around integrating embedded CT models—are critical to the success of students and schools (Johnston et al., 2018; National Research Council, 2007); we center these perspectives in this research.

Drawing from Bandura (1977), teachers first must have confidence in their own abilities to be able to effectively teach something new. Therefore, we asked the following research question: What supports do educators need to increase their confidence and perceived ability to teach CT in grades 3–8 within the context of a citizen science program?

iWonder

This research was conducted in the context of iWonder (formerly WeatherBlur), a program supported and facilitated by a non-profit organization: Maine Mathematics and Science Alliance. iWonder staff collaborate with teachers and scientists so that students can complete a year-long STEM-based citizen science investigation tied to their own communities. Past projects have included studying the effect of weather on the timing of maple sap production and the presence of microplastics in drinking water. iWonder includes curriculum materials, PD, community partnership facilitation, and student and teacher assessment. iWonder utilizes an interdisciplinary approach of combining place-based education pedagogy, citizen science methods, and CT to support students' STEM, environmental, and social and emotional learning outcomes. Early iterations of the program resulted in several positive outcomes for students, including improved graph interpretation skills (Kermish-Allen et al., 2019).

CT was added to the curriculum in 2019 and is presented to the teachers in iWonder as a set of problem-solving skills that can be integrated across the curriculum, but that fit particularly well with citizen science. PD and curriculum emphasize how CT can be used across all aspects of iWonder, from designing investigations to analyzing and presenting data for community change. Both "unplugged" and technology-based lessons highlighting CT components were modeled with teachers in PD sessions. For example, the algorithm design principle was highlighted as classrooms created their protocols to collect data (unplugged applications). The pattern recognition principle was highlighted as classrooms utilized data visualization software to explore their findings (tech-based applications).

Teachers participating in the program had access to year-long support from the project staff through a variety of formats. Prior to the school year implementation, teachers participated in a virtual PD session over two days that introduced CT in citizen science projects and gave time for collaboration with peers to envision how CT may be actualized in their own classrooms and exchange strategies. Throughout the year, the program staff reconnected with teachers through weekly one-hour Zoom check-ins and individual one-on-one support. Twice a year, structured half-day virtual PD sessions were held to respond to emerging needs related to CT. One session in Fall 2021 provided a refresher on CT, a sample activity to demonstrate applications of CT, and an opportunity to brainstorm how CT could overlay onto classrooms' investigations. A second session in Spring 2022 involved teachers working with data and practicing using a data visualization platform called TUVA.

Teachers also had access to a suite of digital resources to support the integration of CT into their investigations. CT Bytes, or mini-lessons, were designed to support students' CT skills. They targeted a particular component of CT (i.e. Algorithmic Thinking, Decomposition, Abstraction, Pattern Recognition). The CT Bytes include hands-on activities, links to resources, and custom-created slides for in-person or remote learning.

Methods

Research Participants

This research examines data generated by 22 female in-service teachers teaching in the United States. Most taught in one state within the New England region of the U.S., and a smaller number taught in two other states in the southeast region of the U.S. The teachers taught grades three through eight; had between one and 35 years of teaching experience (14 years on average); and had between zero and five years of experience with iWonder, specifically.

This study took place during the COVID-19 pandemic, and thus teachers were operating under considerable stress. Nonetheless, they completed the program and research activities, although they did bring up challenges due to transitions between in-person and remote learning and how that affected their investigation plans.

These teachers included generalists and specialists working in schools serving students from varying socioeconomic levels. They are similar to the average elementary or middle school teacher today—a middle-aged, White, English-speaking woman who has been teaching for over ten years (National Center for Education Statistics, 2021).

The teachers worked within broadly similar curricular structures. All taught science using NGSS-aligned standards, with some variation in how standards were prioritized based on state and district priorities. Elementary teachers in this study taught all subject areas, including science and math, some middle school teachers taught science only, and others taught both science and math. However, iWonder involved all subject areas as students were designing their own investigations, researching their questions, and collecting, analyzing, and visualizing data in addition to communicating their work to the wider school community.

Data Sources

We collected multiple data sources related to what teachers express and consider CT within iWonder and their experiences with the curriculum and PD. Data collection occurred through virtual methods due to COVID-19 and teachers' geographic distribution. We collected various data to investigate the patterns within the levels and contexts of the case. All data were anonymized using identifying numbers and we describe the school communities in the most general context.

Survey

Surveys include pre-post measures from Bower et al. (2017) about the importance of developing children's CT skills and teachers' confidence in supporting this. Open-ended items adapted from Yadav et al. (2014) address teacher understanding of CT, how it relates to other disciplines, and how it might be integrated into iWonder. Finally, pre-post measures adapted from Yadav (2014) address teacher knowledge, comfort, interest, and application of CT.

Survey questions were delivered to the teachers near the beginning of the research project via SurveyMonkey software and again after the project at the end of the school year.

Semi-Structured Individual Interviews

Video recordings of approximately half-hour-long semi-structured interviews with each teacher were conducted at the beginning and end of the yearlong program. See Appendix A for interview questions. The interviews were conducted and recorded via a virtual face-to-face online software service like Zoom or Google Meet so that the interviewer and interviewee could hear and see each other during the interview. The design of the interview setting was such that the interactional components of discourse (Hufnagel & Kelly, 2018) could be attended to. Verbatim transcripts were constructed from the video recordings. The teachers provided personal, authentic, and valuable data to consider and reminded us how deeply teachers frame their work and profession through their goals for students (Miller-Rushing & Hufnagel, 2022).

Researcher Memos

Notes and memos constructed by the researchers both during and after teacher interviews were considered as part of the data created during this research project to encourage constant comparative analysis, which aids "in generating a theory which is integrated, consistent, plausible, and close to the data" (Glaser, 1965, p. 437).

Method of Analysis: Qualitative Descriptive Case Study

To answer the research question, we used an empirically-based qualitatively-derived descriptive case study (Patton, 2015; Yin, 2012, 2017) via a linear but iterative process of plan, design, prepare, collect, analyze, and share (Yin, 2017). When considering a case study approach, defining the case is critical. The boundary of what phenomena is being studied is necessary to explicate and clarify throughout the work (Patton, 2015). For this project, the data associated with each teacher was considered, but each teacher was not an individual case. In other words, this was not a cross-case analysis. This project is a case study whose boundary is the teachers participating in iWonder, and we consider the discursive expressions of what is critical to teachers' confidence and perceived ability to teach CT as the phenomenon.

We conducted this case study from July 2021 through June 2022. The analytical frame of this case study was for a rigorous analysis of data collected from 22 teachers. We highlighted patterns within this group of teachers and tied the findings to the group norms (i.e., case), constructing a descriptive case about how CT is considered and utilized by the teachers. The case analysis required interpretation, not statistics, to find the overall storyline. It was important to develop strong, plausible, and fair arguments supported by the data (Yin, 2017).

The data were analyzed through an iterative and abductive coding process (Agar, 2006; Yin, 2017) to create a thick description of the case (Geertz, 2008). This analytical process is informed by discourse analysis-based methodological frameworks (Gee, 2010; Mishler, 1986) to discover how teachers conceptualize and operationalize CT during iWonder.

We used an inductive coding process based on a heuristic theoretical framework, coding as a method of discovery (Miles et al., 2014). Informed by Saldaña (2015) and Miles et al. (2014), we coded the highlighted data in four major stages—first, second, third, and synthesis cycle coding through a collaborative and iterative process among the researchers. The raw data was kept in Microsoft Excel files and the highlighted data was then copied and transferred over to Dedoose software to then be able to more easily track patterns and conduct analysis of the data (Dedoose, 2021). An example of this process can be seen in Table 1. **[INSERT TABLE 1]**

For a code to be accepted, the researchers discussed the data and the potential code together, and only when the coding decision was unanimous was the code created. Thus, coding occurred through a co-coding process. See Appendix B for example third cycle CT codes.

Due to limited space to describe the findings from this data, we highlight the results below that we feel best address our research question after considering the case data. The results underscored in this work reflect the prominence of these results within the data. Those patterns of prominence were identified after looking at the entirety of the data iteratively and analytically. We analyzed discursively-created third-cycle codes by looking across all data sources. We did not quantify these results as data points within each finding but instead went back to the data again and again in an iterative cycle to consider how the teachers as a whole case expressed what supports they need to increase their confidence and perceived ability to teach CT. This process of breaking apart the data and rebuilding the data into a synthesized ordered whole is an important part of the research process (Bazerman, 2006). This process was done iteratively and abductively by staying close to the data, not in an a priori code counting process.

Researcher Reflexivity and Positionality

We positioned ourselves within the methodology of this research because, as the researchers, we are part of the entanglement and intra-actions (Barad, 2003) that occurred to help complete this work; we are a part of the social network that we are studying. The biases we bring to this research include a belief that teachers are professionals who are expected to do the impossible on a daily basis. Reflexively, we can see that some of our understandings are informed by previous professional experiences, including as a former elementary teacher and a science education consultant. Our work is undergirded by a value for giving voice to those not often heard (but often written and spoken about) in education research: teachers.

Results

The teachers in this study were enthusiastic about integrating CT into their curriculum. They acknowledged the positive impact of the summer PD prior to program implementation on setting them up for success. One teacher noted, "I have a better idea of how to introduce the CT to the kids. So that was helpful. Because I knew about it last year, but I wasn't quite sure how to get it in there." (Teacher M6, grades 3-5, pre-interview). Another teacher stated, "I really like that CT. The way we were learning about it, that was pretty valuable information. [The] right application." (Teacher D1, grade 5, pre-interview).

Teachers also had success across the year in integrating CT, citing positive student outcomes. Teachers noted that their students improved their skills. For example:

> I could see how they could find the algorithms of things and that if one thing didn't work, then they could try something different and then plug it in to see if it worked. And we've tried to explain that scientists test several things. (Teacher S2, grade 5, post-interview)

Another teacher explained:

> I think they were good at breaking down information and seeing what they need. But I think they were more aware of what that meant, and maybe more aware that they were doing it because we had talked about, "You have a problem and this is how you go about it and you break it down and then you put it back together." (Teacher M6, grades 3-5, post-interview)

Overall, the teachers expressed that the supports that were critical to their confidence and perceived ability to teach CT were a) a program that is the "just right" level of scaffolding and support, b) a program that provides options and individualization, c) an internal personal identity that embraces a process of continual innovation and learning, and d) an educational system that is encouraging and supportive of the effort and creativity it requires to attempt innovative and intensive programs such as iWonder. We elaborate on each theme below.

Teachers need scaffolds and supports that are at the "just right" level to implement new-to-them curriculum effectively.

Teachers expressed that they were either unfamiliar with and/or uncomfortable describing what counted as CT. Thus, what helped them implement a CT approach into iWonder was getting scaffolding at the right level for their need.

One of the teachers talked about needing just right support in a succinct way when they said, "I am always concerned with adding new things to class, I have very specific things I need to teach, and anything I add needs to complement what I am teaching." (Teacher D1, grade 5, pre-survey). This teacher addressed their specific needs at the beginning of the program. They articulated that without getting those specific needs addressed, the program would be challenging and looked for specific support to better reach alignment between their needs when adding new curricula and their overall teaching goals.

Another example of a teacher expressing a "just right" support need occurred when one teacher commented on needing a team of people to access as an ongoing resource. After an iWonder PD session, she said, "I've got a Go-To team, and I'm super psyched" (Teacher A2, grades 6-8, pre-interview). This teacher even mentioned looking forward to learning more about Tuva, a software program to help with data analysis:

> Math was—is not my strength, to be honest. You know, I feel okay with basic stuff, but like to dive into Tuva, I'm going to need training and support. So, I look forward to the PD on that. I'm probably looking for coaching, you know, via some workshop with Tuva before I really get into it with kids. (Teacher A2, grades 6-8, pre-interview)

This teacher is expressing that not only do they need a team of people they can go to for the help, support, and resources they need, but they also need and expect to be able to access additional PD learning experiences through this team to learn specific software that will help with their teaching of CT. This teacher also expresses specifics of the support format (i.e., coaching, workshops), further leaning into the "just right" level of support needed.

Another teacher highlights how the PD on CT allowed an intentional scaffolding of content with their prior experiences:

> The session on CT, I was confused about what that was before I came to the Institute... But it was exactly right. When they started talking about it, I was like, 'Oh, we do this. We just don't give it that name.' But I am interested in that idea because it kind of gives us a systematic way to be sure that we're helping to guide kids through that. Like, the part about abstraction, is something that could be developed in terms of coaching kids through it. This would be a neat community to do that with. (Teacher C3, grade 4, pre-interview)

Another exchange between researcher and teacher highlighted that sometimes the process of determining what is "just right" for teachers requires work by community partners before, during, and after the teacher uses the curricula. During an interview, the teacher says that they were curious why the iWonder staff had them take a small pre-test well before embarking on the PD training. The researcher responds:

> Everyone, regardless of experience with iWonder, teachers across the board are coming in with vastly different experience levels with computational thinking. So, if we know where you guys are at then we can, like meet you there, right? Yeah, it's not a test like, "Oh, you don't know enough" but more like, "Oh, great. Now we know where you are." (Researcher/interviewer during the interview)

The teacher replies:

> That's fantastic. Thanks. I was just wildly curious…it sounds like exactly what we do as teachers. . . before we teach a unit and after. (Teacher R1, grades 5-9, pre-interview)

Teachers express that scaffolds need to be "just right" for their needs and can be as specific as a particular training or as broad and encompassing as assessment and communication. Throughout the case, they expressed that their specific needs should be considered.

Teachers need a program that provides options and individualization.

Throughout the case, teachers described how the flexibility of iWonder and the individual attention from the program's staff were important for supporting implementation in their classrooms. One teacher remarked about modifying CT to meet the needs of their students:

> I didn't use that terminology with my students. However, we were definitely engaging in everything that it embodies. We looked for patterns when we were looking for a question … So I feel like we were doing all those things. (Teacher C3, grade 4, post-interview)

This teacher took the CT concepts presented within the context of iWonder and individualized them by presenting the concepts rather than focusing on the terminology. Interestingly, this same teacher (C3) underscored this point in their post-survey:

> The vocabulary with the computational thinking felt too much with an already big project with fourth graders. Having said that, we did do it. We did an authentic inventory of our environment and looked for patterns. They identified wonders around those patterns. We spent a lot of time determining what is important. (Teacher C3, grade 4, post-interview)

This teacher felt this was an important point to make- that the vocabulary of CT was too much to consider for their classroom needs at this time, yet they were still able to complete the program even without strict adherence to all of curricula and suggestions, including vocabulary use. This teacher expresses that the project was authentic despite their mediation of the programs' learning goals. And thus, they highlight that teachers need a program that they feel they can individuate and mediate to be successful and meet the needs of that particular classroom.

Having an internal identity that embraces a process of continual innovation and learning was helpful when trying to implement a new curriculum.

Throughout the case, we found a pattern of teachers expressing their teacher-related identity towards learning and growth as a key factor determining how they engage with the curriculum. These comments were often shared as an aside when teachers commented on what they need to teach more effectively, how they integrate the curriculum into their practice, or when they consider the content of the curriculum. For example, one teacher expressed that:

> My teaching has always been centered on nature-based and place-based teaching. In the past, that has been low-tech. As I teach more science, I can see some very interesting tools for some of our work. I now see that the two can complement each other nicely. I feel like I need more experience to gain confidence. (Teacher C3, grade 4, pre-survey)

This teacher explains the ways of teaching that undergird their practice; that they have a personal foundation of teaching a type of curriculum that aligns with iWonder: nature-based and place-based teaching. Along with noticing additional ways to align this new curriculum with their already established teaching practice, they also mention that they need more experience regarding CT to have the confidence to integrate it effectively. This teacher is highly reflective and expresses an identity of embracing learning and growth.

Another teacher describes how they had already internalized some of the CT strategies as part of their teaching practice when they expressed,

> I always personally like to have them...I didn't call it computational thinking, but I always already had them do part of what you're talking about last year. For me, it's just new terminology more than things that I'm doing differently. (Teacher K1, grade 5, pre-interview)

An additional teacher describes their excitement for the program related to their identity:

> I do lots of investigations with my kids developing progressions and systematic ways for us to be doing it so it sticks. It's not just a one and done. So I'm very excited about it. I guess it's just right up my alley. (Teacher C3, grade 4, pre-interview)

Implementation and integration of new curricula are more effective when teachers work within an educational system that is encouraging and supportive.

We found that teachers are more willing and able to have the agency to try new and interdisciplinary curricula like iWonder when they are working in a system that is encouraging and supportive. The teachers who had an internal desire to continue learning and innovating and worked within a system that supported them to take risks and try new ideas expressed more willingness to embrace CT in a project like iWonder.

One of the ways the system was encouraging and supportive was by allowing teachers to take the time to attend and participate in PD and ongoing school-to-school planning for curriculum implementation and integration. The teachers, across surveys and interviews, expressed that attending trainings or institutes run by the community partner organization and working with other schools and teachers on this curriculum was critical to integrating this curriculum into their practice. For example, one teacher expressed their belief in the benefit of attending trainings and working with other teachers across schools when they said,

> I thought it was a good summer institute this year. It was great to be able to meet with the other teachers from both [school 1] and [school 2] because we do the same stuff. We work together and, you know, being able to talk with you all [i.e., iWonder team] and then talk with them one-on-one really helped a lot. I think we had some good ideas. (Teacher D1, grade 5, pre-interview)

Teacher S1 also noted the importance of working collaboratively with other teachers as important for their ability to teach iWonder. They expressed that working collaboratively with other teachers while in PD opportunities (i.e., breakout rooms) and forming ongoing connections with these teachers was valuable to their implementation of the curricula:

> I really liked getting together in those breakout rooms and having other teachers to talk to. Some of the teachers that had like, already done this and how they used it in their classrooms, like that was really helpful to hear. So yeah, those pieces of it were really great and forming those connections too, which I think is important with teachers that have already done this. (Teacher S1, grades 5-9, pre-interview)

Another teacher described the impact the program staff had on their ability to implement the program, "The whole team of the iWonder staff was awesome in getting the information to us, being patient with us, telling us things we can do, reminding us of different things that [we] need to that are coming up." (Teacher E2, grade 5, post-interview). A system that encourages and supports its teachers to do the hard work to implement a new curriculum into their practice makes implementation more effective: a clear pattern throughout the case.

Finally, one teacher commented how helpful it is to consider doing this CT program because their "district is one-to-one Chromebook use, most of our students and teachers use computational skills each day. Our district is one of the best technology districts in the state."

(Teacher E2, grade 5, pre-survey). This teacher underscores that trying to do this program would be more challenging without the technological supports already in place across their district. iWonder requires students to work with data, analyze data, and communicate about data, and this teacher feels implementing these curricular expectations is afforded when their district is supportive with necessary technological tools and supports.

Discussion

We were able to answer our research question by centering the teachers’ discursive expressions throughout the case. Teachers shared what supports they need to increase their confidence and their perceived ability to teach CT in grades 3–8. Just as Ketelhut et al. (2020)’s research found, the teachers in this study were enthusiastic about integrating CT into their instruction and were able to do so with more integrity in part due to the high-quality PD experience that was part of the program. We were able to utilize and leverage their enthusiasm, professionalism, and knowledge to support the body of literature in better understanding what works when implementing an interdisciplinary STEM-based CT curriculum.

Across the case, teachers expressed that the supports that were critical to their confidence and perceived ability to teach CT in such an integrated and interdisciplinary way were a) a program that provides the “just right” level of scaffolding and support, b) a program that provides options and individualization, c) an internal personal identity that embraces a process of continual innovation and learning, and d) an educational system that is encouraging and supportive of the effort and creativity it requires to attempt implementing innovative and intensive embedded CT programs such as iWonder.

One of the central findings that teachers need to be scaffolded at a “just right” level requires time and attention to teachers’ needs as individuals. Achieving a “just right” level of support is no easy task and requires ongoing assessment and communication, a heavy lift for many administrators and organizations that work to support teachers. PD providers need the capacity to spend time before, during, and after the training they provide to teachers and on an ongoing and iterative basis to know what the teachers need as their learning and curriculum implementation progresses. This work attempts to call out what is working for teachers, including having a supportive team, scaffolding with prior experiences, flexibility in programming, and ongoing communication and assessment. We hope organizations and administrators that do the critical work to make teacher learning at a "just right" level can gain some insight and more effectively tailor their efforts and capital. Just as we encourage teachers to differentiate their classrooms (Deunk et al., 2015), we also need administrators and organizations that support differentiated teacher learning based on the expressed needs of the individual teachers they work with. However, just as the framework document that undergirds the NGSS emphasizes, it is depth, not breadth, necessary to learn complex and interrelated STEM topics (National Research Council, 2012). This idea of supporting teachers deeply in ways that feel genuine, authentic, and needed holds true for teacher learning as well.

The "just right" level of support is exemplified in these data by how teachers viewed the terminology of CT and related that to their classroom implementation. Some teachers were not familiar with the practices of CT, others were able to identify that they were doing CT but hadn't used the terminology, and others were more familiar and ready to engage in more advanced applications (i.e. TUVA software). No matter where teachers were on their CT journey, the program provided varying levels of support and scaffolding to meet them where they were and support them in improving and strengthening their CT instruction. Most teachers were able to relate their existing work in the classroom in some way to the CT concepts discussed in the PD and this became an accessible entry point for further growth.

Another finding we would like to highlight is that a teacher's identity, specifically an identity that embraces a process of continual innovation and learning, is an aspect of why and how teachers integrate and implement new and challenging curricula. Identity is an important component to consider when researching how and why teachers do what they do (i.e., teacher agency) because their professional identity plays a role in how agency is expressed (Edwards, 2015; Eteläpelto et al., 2013; Martin, 2017).

Throughout the case, the teachers expressed that they felt compelled to be part of iWonder for various reasons. Even so, their pattern of expression centered around a desire to innovate and learn and to enact their professional agency, often citing that they were motivated to provide the best experience possible for their students. It is beyond the purview of this research to deeply consider the role of each teacher's professional identity in the enactment of iWonder. However, it is important to note that identity emboldens agency (Holland et al., 1998). Suppose STEM education researchers want to know why and how teachers enact their agency. In that case, we need to consider the interactions between teacher identity, agency, and the contexts they are engaging in (including curricular and programmatic contexts) (Richmond, 2016).

Further, it is important to contextualize these teachers' expressions within a system. That system can both support and constrain teacher agency (Biesta & Tedder, 2006). Teachers within this case have professional lived experiences that are emblematic of the K–12 public school system in the United States and uniquely individual experiences. However, what is important to highlight for this research specifically is that even while dealing with COVID-19, teachers still were making professionally agentic moves (Eteläpelto et al., 2013) to change the way they were currently teaching in their classrooms to bring in something new: CT. Teachers are part of a complex ecological web of structures that they affect and that affect them (Archer, 2003; Priestley et al., 2015). We can learn from them by centering their voice and needs, and then leverage this learning to assist others in making self-efficacious choices in implementing interdisciplinary STEM curriculum integrating CT content.

Meeting teachers' PD needs is challenging when opportunities, resources, and colleagues are limited and spread out physically from one another (Sandholtz & Ringstaff, 2013). For example, as Killen et al. (2020) pointed out, communities of practice can help elementary teachers understand embedded CT more effectively. However, if teachers are not able to be part of learning experiences like communities of practice, because they are unable to be near enough to other educators facing the same teaching struggles, do not know, or are not supported in developing communities of practice outside their schools and districts, then these educators are even more constrained in trying to implement new content like CT. The opportunity to bring teachers together from across schools and districts is elevated in this project and highlighted by teachers as a part of a supportive educational system, a core finding of this work.

The teachers' discourse expressed the contexts they were navigating and mitigating and clarified the design elements of the PD experience that helped teachers feel more confident in their ability to teach CT, and made implementation more effective. It is important as researchers that we not only listen to their discursive expressions of what works but also act on those expressions. Teachers' CT understanding, pedagogical capabilities, technological know-how, and confidence can be improved through targeted PD (Bower et al., 2017). Future curriculum and PD should be planned from the beginning with the needs of the teacher in mind so that teachers can ultimately draw on lived experiences that give them the confidence and self-efficacy to try new approaches, like CT, in ways that enable them to express their agency (Avraamidou, 2018; Nolan & Molla, 2017; Richmond, 2016).

We recommend that STEM education researchers center the teacher not only as a research participant but as a knowledgeable source of what works in education. By centering the teacher voice in the research, not only are we highlighting those that most profoundly affect the youth across our schools, but we are highlighting their experience, wisdom, and lived experiences as those at the center of the classroom experience.

If we are to achieve enhanced and increased CT skills for our youth, which is both desired and challenging to implement for elementary and middle school grade teachers (Bower et al., 2017; Killen et al., 2020), then we must consider the affordances and constraints of the interdisciplinary nature of CT. CT is an interdisciplinary way of thinking based on solving real-world problems with data and evidence (Rabiee & Tjoa, 2017). Thus, it should be embedded across all subject matters, especially as part of STEM subjects (Wang et al., 2021). To be effective, we cannot silo the learning or the teaching of CT. CT should not be just a topic for math and science teachers to consider; it is a valuable way of thinking across educational experiences for all our youth. Elementary and subject-specific teachers in middle school can all learn about CT and embed this way of thinking across classrooms. There are many opportunities to do so. There could be school- and district-wide learning experiences for teachers to embed CT into their curriculum. There could be collaboration across grades, schools, districts, and subjects and in partnership with community organizations to help teachers discover what works for them and their students. By looking at CT as a critical interdisciplinary topic, we can move towards embedded high-quality CT curricula that span grades and subjects, and supports student thinking.

Conclusion

This study was conducted during a global trend in introducing CT into school curricula (Barr et al., 2011; Liu et al., 2011; Voogt et al., 2015). Teaching high-quality, embedded CT is challenging, especially in the younger grades (Killen et al., 2020). The professional knowledge-building of classroom teachers related to CT is a critical component to achieving the goal of increased and enhanced high-quality CT curriculum across K–12 (Hestness et al., 2018). This paper presents one such avenue to do so: through a place-based citizen science project.

Teachers, and their professional identity, are part of a complex and highly contextualized structure-agency dialectic (Buchanan, 2015; Richmond, 2016). By creating educational systems and structures that encourage and support teachers in their curriculum integration work, the outcomes will be more successful and effective. We need to do more as researchers to consider how our school systems afford and constrain teacher agency and teacher learning since they are the lynchpin of our educational system (Andere, 2015; Ingersoll et al., 2017). We also highlight that the interdisciplinarity of CT can be an opportunity to embed it across grades and subjects.

We would also like to highlight that these findings point out that supporting teachers in “just right” ways can happen creatively. For example, the teachers expressed that implementation and integration of new curricula are more effective when teachers work within an educational system that is encouraging and supportive. Often the systems we expect teachers to work within are the typical K-12 classroom-based systems within districts or states, or systems that are supported by the teachers and administrators who work within the walls of the school. This research points out that that an education system can, and perhaps should, look outside its usual parameters to be supportive in ways that can achieve these “just right” levels. Perhaps, like iWonder did, deeply collaborating with organizations that support community learning initiatives and creating teacher learning communities that span districts and states can be just the start of generating a whole host of specific ways of meeting the "just right" needs of teachers and their classroom's learning goals. This conclusion might not necessarily be novel, but it is so rarely achieved we feel that it is important to reiterate these findings. The teachers in this case stated clearly what they perceived as helpful for implementation of CT within their classrooms.

Although we feel these findings add to the body of knowledge on STEM education, CT integration, and teacher PD, we acknowledge that there are limitations to this work. Due to the constraints of the program's resources, only a small group of teachers are implementing this particular curricular program, iWonder. Even though the majority of teachers who taught iWonder also took part in the research and evaluation of the program, our work is based on a small group of only 22 teachers. We also acknowledge that our chosen method using qualitative discourse analysis is effective at describing the case available, it does not provide enough data to think about the generalizability or replicability of these findings. For that, we would need to ask different research questions with a different data set and utilize different methods. In addition, we acknowledge that this study took place during the COVID-19 pandemic in which teachers experienced and expressed significant challenges and uncertainty, which certainly may have had an impact on the data collected.

Our world is full of issues that could use the evidence-based problem-solving methodology that CT provides. We encourage CT to be an embedded part of every teacher's practice. To do this without putting one more expectation on an already overburdened and under-resourced profession (Carter Andrews et al., 2016) means every educational researcher, administrator, and community organization that works to support education and teachers needs to use more of their resources and capital to center teacher voice and act on those critical discursive expressions that can then support teachers in "just right" ways.

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Table 1. Example of Discursive-based Data Showing Coding Steps

Raw Data From	**First Cycle Code** (highlighted data section)	**Second Cycle Code** (attending to smaller chunks of important discourse within the highlighted data)	**Third Cycle Code** (assigning a label that describes the highlighted data accurately)	**Synthesis** in Researcher Memo
Teacher, A1, grades 3-8, presurvey	"I've been teaching this specific to computer science for a long time, and my style of teaching science aligns closely with that type of thinking as well."	"teaching CT long time" "teaching style aligns with that type of thinking"	"Experience with CT"	Looking across the data we observe various ways teachers express their experience with CT. Whether or not they call it CT, and whether they feel comfortable and/or confidant about CT, they express their experience with CT in various ways across the data. (Researcher memo)
Teacher, A2, grades 6-8, presurvey	"Need to know more about computational thinking. This is new vocabulary to me."	"need to know more about CT" "New vocabulary"	"Experience with CT"	

Appendix A

Pre- and Post- Interview Questions

Pre-Interview Questions

- How did the Summer Institute go for you? What was the most valuable part of the summer institute for you?
- Our focus for iWonder this year is supporting integration of Computational Thinking and Computational data analysis skills. What has been your experience as a teacher with these topics?
- How do you envision CT fitting in with iWonder, given your prior experience with the program? (OR how does CT fit in with science or citizen science?)
- How are you feeling as far as having what you need to implement iWonder this year- especially the CT components?
- What do you still need support with/clarification on?
- What are you most excited about as you begin iWonder this year?
- What are you most concerned about? What barriers are you anticipating?
- What else are you thinking of as you begin iWonder this year?

Post Interview Questions

- How has your experience been overall with iWonder this year- especially the linkages to computational thinking, which is a new component?
- Did you notice any student impacts as a result of their participation this year?
- Were there specific challenges or barriers you encountered as part of the implementation in your classroom this year and making connections to CT?

- If yes- Can you tell me about those challenges and any strategies you used to overcome them? Did those strategies work?
- What helped to support your classroom implementation of iWonder and connections to CT? These could be activities, training, resources, etc. What was the most helpful?
- What additional support do you need as a teacher to integrate CT into [iWonder effectively? What types of professional development would you like to see?
- How would you improve the iWonder program in the future?
- Any other feedback about iWonder?

Appendix B

Example Second Cycle/Process Code Titles and Descriptors for Computational Thinking (CT)

Title of Code	Description of Code
CT Can Show Up In	Refers to where CT can show up, specific subjects or across curriculum
CT Means/CT Is	Captures how teachers are defining what CT means to them
Critical Thinking	CT involves critical thinking ("critical thinking" is not defined), or reference to a "process of thinking." Can include reference to "logic."
Problem Solving	Refers to a problem-solving process; how one thinks about a problem; thinking about a problem as a series of steps
Real World	Refers to a "real world" connection or application of CT, CT process
Scientific Process	Refers to asking questions, drawing conclusions, using supporting evidence as part of the CT Process
Technology	Refers to CT using/involving technology (programs, iPads etc.)
Experience with CT	Teachers' experiences with CT, whether they call it "CT" or not
Long term	Teacher has had long "term experience" (self-described) with CT
Need CT training	Comments on a need for CT training for effectiveness/comfort
Teaching Style Aligns with CT	Teacher expresses that their personal teaching style connects with CT process/components (whether they call it CT or not)

Outcomes of CT	Refers to "ways of doing things" or "helping to learn/understand." Inferred by coders to mean that CT or knowing about CT can result in specific outcomes, such as increased efficiency / ability to understand