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Teacher Change Following a Professional Development Experience in Integrating Computational Thinking into Elementary Science

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Abstract

Computer science and computer science education are marked by gender and racial disparities. To increase the number and diversity of students engaging in computer science, young children need opportunities to develop interest and foundational understandings, including computational thinking (CT). Accordingly, elementary teachers need to understand CT, and how to integrate it into their practice. We investigate how to best support elementary teachers in learning to integrate CT into their science teaching through a CT professional development experience for elementary teachers. The professional development consisted of two parts: a professional development workshop and a science teacher inquiry group. In this study, we sought to understand if and how teachers' views on integrating CT into their teaching practice changed following their participation in a yearlong professional development experience on CT. Based on our analysis, we offer suggestions for future research and implications for the design of professional development for integrating CT into science education.

Keywords Computational thinking · Teacher education · Science education · Elementary · Professional development

Computational thinking (CT) has become steadily more important as a way of thinking about solving complex, open-ended problems. Until relatively recently, CT's importance was limited to those engaging in computer science. In 2006, Wing argued that CT is something that everyone needs to do, not just computer scientists. Her argument has strengthened in the last decade with the growing ubiquity of computing—the power of CT, once limited to computer scientists, can now be beneficial to people in all disciplines (Barr and Stephenson 2011; National Research Council 2010; Wing 2008; Yadav et al. 2017a). Additionally, this permeation of computing into practices beyond computer sciences has created an economic argument for pushing for computing education in the general population (D'Alba and Huett 2017; National Research Council 2010). As industries and sciences become increasingly computerized, the push for a computationally competent population intensifies. Therefore, there is a need for a population that can engage in CT—a need that can be addressed through education.

However, our efforts to integrate CT in education cannot be isolated from the social issues that surround computing education today: we must prepare *all* our students to engage in computation regardless of their gender, race, or ethnicity. These efforts to diversify computing education are supported by economic, social, and moral reasons. First, if computing jobs are in increasing demand in the economy, then integrating more students from all backgrounds would allow for a larger pool of computing professionals. Second, as computing becomes increasingly ubiquitous, more systems rely on computing to collect, analyze, and use data to inform decisions. The lack of diversity in computing professionals can lead to systems that fail to consider social implications of how that data is collected, analyzed, and used (e.g., Angwin et al. 2016). Third, if we predict that computing jobs will be both increasingly available and some of the most lucrative professions in the future, then failing to provide opportunities to students from all backgrounds to enter the field of computing would only deepen the racial inequality that exists in the USA.

But, although we have established the need for CT education, the research community has not reached consensus on a definition of CT—particularly needed for driving integration into education contexts (Buss and Gamboa 2017; Grover and Pea 2013; National Research Council 2010). Wing (2006) described CT as "solving problems, designing systems, and understanding human behavior by drawing on the concepts

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fundamental to computer science" (p. 33). Since then, leaders in the fields of computer science and education have defined CT in a variety of ways. Many conceptualizations of CT include at their core a notion of formulating and solving problems in ways that (can) leverage the power of computing (Aho 2012, Barr and Stephenson 2011; Cuny et al. 2010; International Society for Technology in Education (ISTE) 2016: Rambally 2017). Some definitions of CT have also included skills, competencies, and tenets intrinsic to CT. For example, Barr and Stephenson (2011) described competencies involved in CT, such as problem decomposition, abstraction, and automation, as well as affective components, such as confidence in dealing with complexity and persistence with difficult problems. Sadik et al. (2017) reviewed and summarized CT tenets suggested in the literature and noted that they generally included problem-solving, problem decomposition, pattern recognition, abstraction, algorithms, and evaluation. They also noted that there persists a need for a more consistent definition of CT, particularly for its inclusion in education.

Regardless of the lack of consensus from the research community of what constitutes CT, countries around the world—and states within the USA—have begun formal efforts to include CT into compulsory education (Bocconi et al. 2016). But, with CT becoming increasingly valued as an important part of education, its inconsistent definition may create confusion among educators regarding what CT looks like in practice (Voogt et al. 2015). Even if the research community were to reach a consensus on an abstract definition of CT, teachers need and demand more specific instances of CT to include it in their lesson planning and instruction. Therefore, efforts to incorporate CT broadly must help to clarify for K-12 educators how CT is relevant to their existing classroom practice and instructional goals, and how they can be best supported in learning about CT and related pedagogies.

Our project, Computational Thinking in Preservice Science Teacher Education (CT → PSTE), is investigating how researchers can work alongside teachers to develop these instances of CT in education. Specifically, we focus on science teaching, because the strong connection between CT and science makes this discipline a natural field for exploring initial ways to integrate CT into classroom instruction. While we have specified that CT is increasingly relevant for all disciplines, this increase is significant in STEM. Sciences are becoming increasingly computational, as illustrated by the emergence of computational branches of traditional sciences (e.g., computational biology and computational astronomy).

Our project has also chosen to focus on elementary education for two reasons. First, we believe that students should be exposed to CT early, so that their interest in computing is promoted while students are developing their identity and before they begin making early career choices (Tai et al. 2006). Second, innovating within elementary instruction has the potential to reach *all* students. While middle and high schools can provide opportunities for children to engage in CT, these are often available only as after-school opt-in programs or course electives. These opportunities require student interest in computation *before* engaging in CT. Our goal in working with elementary teachers is to help them foster such an interest in their students before they encounter more formal opportunities to engage in CT.

Our project's main goal is to develop a research-based model for preservice teacher education that supports undergraduate elementary education majors in building an understanding of CT and pedagogical knowledge for integrating CT into their science teaching practice. With that aim, we have integrated CT into elementary science methods coursework for preservice teachers and encouraged them to infuse CT into lessons they teach in their field-based internships (1st–5th grade classrooms). However, while our preservice teachers expressed eagerness to engage students in CT, they also expressed hesitation to bring CT innovations to their classroom internships because their mentor teachers were unfamiliar with the concept (Hestness et al. 2018). Therefore, we developed a two-part professional development experience for mentor teachers (MTs). The goal of this new PD experience was for MTs to understand the nature of CT, the importance of integrating it into science education, and the recommendations for CT integration in elementary science classrooms (Hestness et al. 2018). We posited that understanding CT and believing in its potential role in science education would improve MTs support of their preservice teacher mentees (called "residents" in our program) to make first attempts at including CT in their science teaching practice. Our PD included a MT-only workshop plus participation in a yearlong inquiry group in CT—the Science Teaching Inquiry group in Computational Thinking (STIG^{CT})—in which MTs and preservice teachers engaged in CT alongside one another and our research team. The purpose of the STIG^{CT} was to provide a venue to share expertise toward the ultimate goal of creating CT-infused elementary science lesson plans. This paper is about how these MTs changed their beliefs and understandings: their learning around CT, their views on implementing it in their classrooms, and the obstacles they perceived to the goal of integrating CT into formal education.

Literature Review

CT for All Through STEM Education

As explained above, the increasing ubiquity of computing creates a demand for a population that can productively engage in CT. It demands that we work towards CT for All. As we try to satisfy that demand through education, researchers suggest that integrating CT into existing curricula is a promising avenue. This approach would make CT accessible to students even in cases where schools lack the resources for standalone computing courses (Yadav et al. 2016).

Consequently, researchers and policy-makers have begun the process of CT proliferation by concentrating in STEM education. For example, the Next Generation Science Standards (NGSS Lead States 2013) support the infusion of CT into K-12 science classrooms by including CT as one of eight Core Science and Engineering Practices. Further, researchers have argued that STEM is a natural context for the infusion of CT, and have developed frameworks to guide those integrations. For example, Weintrop et al. (2016) proposed their taxonomy of CT practices to integrate CT into high school math and science curricula. For these reasons, our project focuses on integration of CT into science education.

Additionally, to achieve the mission of CT for All, we focus our efforts in elementary education. While research suggests that gaining confidence in computing can develop interest in STEM careers (Orton et al. 2016), many children have no exposure to computer science until college (Wing 2006; Barr and Stephenson 2011). This lack of early exposure to computing is a potential contributor to the underrepresentation of female and minority students in STEM education and careers (Gallup Inc. and Google Inc. 2016; see also Tatar et al. 2017). Because CT has the potential to engage children who are not typically engaged with the traditional STEM curriculum (e.g., through e-textiles; Jayathirtha and Kafai 2019), we contextualize our study in elementary education, where CT can play a foundational role to engage **all** children in computation and help them develop an initial interest for STEM and computation careers (Israel et al. 2015).

Teacher Professional Development as a Dimension of CT for All

Researchers propose that, although not all innovations are successful, those who manage to effect change in education do so—in part—by engaging teachers in fruitful PD (Guskey 1986). Clarke and Hollingsworth (2002) suggested that teachers' beliefs and knowledge are interconnected with their practice. Therefore, if the aim of the PD is to change teacher practice, then, it must simultaneously address teachers' beliefs (for a more detailed explanation of their model of teacher change, see below). Proponents of CT in education suggest that this innovation is no exception—providing support to practicing teachers in integrating CT into their subject areas and curricula is a critical aspect of promoting CT for All (Barr and Stephenson 2011; Voogt et al. 2015; Yadav et al. 2017b).

Previous studies investigating how teachers' beliefs and knowledge around CT change have shown some promising results. In terms of beliefs, research suggests that engaging teachers in CT activities with a "low floor," such as block-based programming, can take away the initial apprehension towards computation (Adler and Kim 2018). Studies also suggest that learning about CT in PD or teacher education programs can help teachers feel more confident about their ability to integrate it into their teaching (Jaipal-Jamani and Angeli 2017).

Other work has centered around teacher knowledge, and how educators learn the definitions and applications of CT for K-12 education—also with encouraging results. For example, Yadav and colleagues showed the different conceptualizations that preservice teachers developed around CT after learning about it within their teacher education program (Yadav et al. 2014). Bower et al. (2017) also investigated how teachers learned about CT by evaluating the persistence of misconceptions around the definition of CT after instruction. Taken together, these studies suggest that engaging in PD or teacher education around CT can be effective at changing teachers' knowledge around the concepts of computation and definitions of CT.

However, the relatively nascent literature of PD around CT leaves some unresolved issues regarding the populations investigated and the formats of PD employed. First, a significant portion of the literature focuses on preservice teachers (e.g., Adler and Kim 2018; Jaipal-Jamani and Angeli 2017; Yadav et al. 2014). While future educators are a logical avenue for long-term change (and the primary focus of our project), there is also a need to prepare current teachers to integrate CT into their classrooms—especially if we consider the ubiquity of computing as not only growing but accelerating. Further, as we indicated earlier in this paper, we have found that when mentor teachers are unfamiliar with the concepts, preservice teachers are reluctant to act on their learning. Therefore, research on how in-service teachers go through changes in beliefs and knowledge around CT could inform the field on how to design PD that can help *all* teachers, nascent and experienced.

Second, the research that focuses on in-service teachers usually takes an abbreviated format of PD. Summer programs and workshops are common formats researchers adopt to bring innovation to teachers who are typically busiest during the academic year. While these approaches can create change in teachers' beliefs and knowledge around CT (Bower et al. 2017), educators could also benefit from prolonged PD that allows time for teachers to grapple with new concepts, experiment in the classroom, reflect on their practice, and receive feedback from researchers (Darling-Hammond et al. 2017). Therefore, to illuminate these gaps in the literature, this study focuses on how in-service teachers' beliefs and knowledge change through a yearlong PD.

Theoretical Perspective: Teacher Change

PD programs, such as those designed to support teachers in integrating CT, require teachers to change their practice.

Historically, PD primarily attempted to change the beliefs and understandings of teachers. But, these efforts were criticized for being “irrelevant and ineffective” (Wood and Thompson 1980, p 374). In an effort to improve the efficacy of PD for teachers, Guskey (1986) proposed an alternative model for change. He argued that exposure to new ideas in outside PD was unlikely to change teacher beliefs unless they were field-tested in the classroom. If the novel teaching strategy yielded desired learning outcomes, teachers would then change their beliefs and understandings (Guskey 1986).

Models for teacher change have evolved from Guskey’s (1986) initial proposition regarding the need for teachers to attempt change in the classroom. In 1997, Clarke criticized Guskey’s model for suggesting that teacher change is strictly a linear process, instead suggesting that change could be cyclic with multiple entry points. Drawing from Clarke (1997), Clarke and Hollingsworth (2002) developed a model of teacher professional growth, the Interconnected Model of Professional Growth (IMPG), with four analytic domains (Fig. 1). The **external domain** refers to sources of information or resources from outside of the classroom. Such resources include money, technology, or time. The **domain of practice** refers to the professional experimentation or the pedagogies that teachers are trying in their classroom. The **personal domain** refers to teacher knowledge, beliefs, and attitudes. That is, how teachers value new pedagogies enacted in their classrooms. Finally, the **domain of consequence** refers to outcomes resulting from implementing a new pedagogy. Such outcomes may include student learning, motivation, or classroom management. These domains are interconnected and non-linear, representing multiple growth pathways. The model suggests that change occurs through *reflection* and *enactment* within and between each of these four domains, represented by arrows in Fig. 1. The entire process of professional growth is situated within constraints and affordances of the change environment.

Although the IMPG was developed over 15 years ago, it has been in consistent use ever since. Previous studies have applied the IMPG to study learning and implementation of novel science pedagogies, such as modeling and argumentation. For example, Justi and Van Driel (2005) studied how science teachers developed knowledge about modeling through PD and a research project in their classrooms. More recently, McNeill et al. (2016) considered the framework to study factors that impact teachers’ use of argumentation in their classroom. Both studies suggested that incorporating novel science pedagogies can be influenced by factors reflected in Clarke and Hollingsworth’s (2002) model. More applicable to this study, Kafyulilo et al. (2015) applied the IMPG to studying the development of collaboratively designed science lessons integrated with technology. Similar to this study, they also asked participants to both teach and reflect on the lessons. In the present study, we applied the IMPG model to analyze the growth of the elementary school MT participants in our CT PD workshops and STIG^{CT}. We hypothesized that this model would highlight where change and growth were facilitated by participant interactions with our project, and illuminate participants’ perceived obstacles to change.

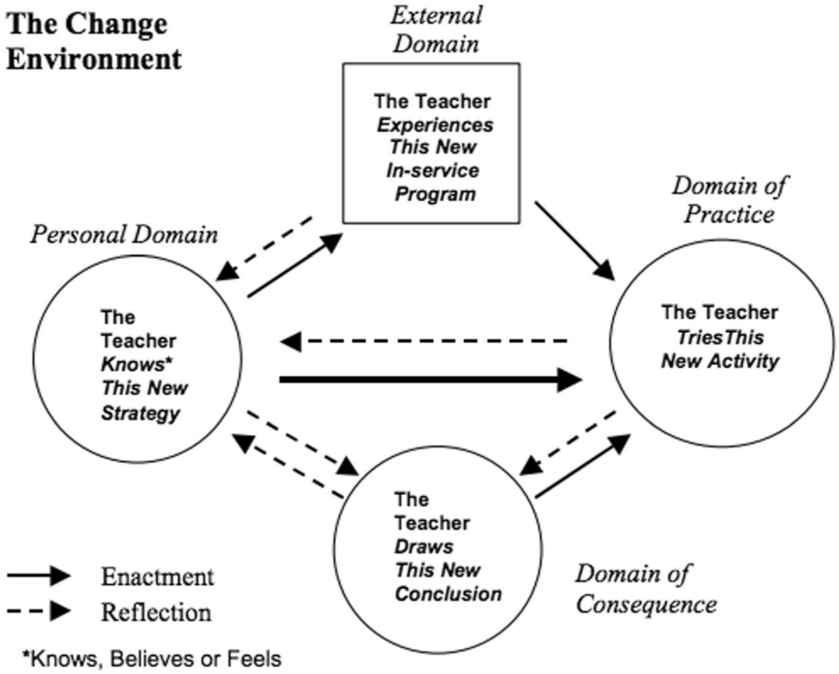

Fig. 1 The Interconnected Model of Professional Growth (Clarke and Hollingsworth 2002)

Methods

We operationalize Clarke and Hollingsworth's (2002) IMPG model in the context of our CT PD experience through qualitative analysis, including a case study of three participating MTs (Creswell 2017; Merriam 1998). For this study, the ***domain of practice*** refers to the professional experimentation or pedagogies related to CT that teachers brought to their classrooms as a result of the computational thinking PD workshops and the STIG^{CT}. In analyzing the domain of practice, we examined how MTs described their envisioned and actual efforts to incorporate CT into their teaching. The ***domain of consequence*** refers to outcomes resulting from implementing CT-infused instruction. In analyzing the domain of consequence, we included both the outcomes that teachers envisioned related to incorporating CT into their teaching, as well as the outcomes that teachers actually observed. The ***personal domain*** refers to teacher knowledge, beliefs, and attitudes about CT integration. In analyzing the personal domain, we interpreted the ways in which MTs appeared to see value in CT-infused instruction for what it uncovered about their students' abilities and what it allowed them to do pedagogically. We draw from a variety of data sources to provide rich insight to our research question, "How did mentor teachers' views on integrating CT into their teaching practice change following their participation in a yearlong PD experience on CT?"

Study Context

Our study took place in the context of a yearlong teacher professional experience focused on integrating CT into elementary science education. This experience consisted of two parts: first, two initial half-day Saturday PD workshops for MTs only and second, seven 90-min after-school sessions for MTs and preservice teachers working with the research team as an "inquiry group." The primary purpose of the mentor-only workshops was to provide similar CT learning activities that preservice teacher residents experienced in their Elementary Science Methods Course so that both groups entered the inquiry group experience with similar CT backgrounds. While we detail elsewhere (Authors 2018) the content and structure of the mentor-only workshops, we provide a summary of activities in Tables 1 and 2. Throughout all the learning experiences, the research team used Weintrop et al.'s (2016) taxonomy for integrating CT into math and science to operationalize CT. While we recognized that the taxonomy was developed for high school science, we believed that its characterization of CT in science would still be useful to explore its integration into elementary science instruction. The taxonomy divides CT into four categories of practices: data, modeling and simulations, computational problem-solving practices, and systems thinking. While some of the language in the taxonomy seem to be shared with other scientific practices (e.g., "data collection" and "investigating a complex system as a whole"), each practice has a computational aspect in this framework—which we attempted to highlight when we used the taxonomy with our participants.

The seven after-school inquiry group sessions, the STIG^{CT}, expanded on the workshops and offered MTs and preservice teacher residents an opportunity to continue their learning together. This aspect focused more deeply on key CT concepts and offered additional opportunities for teachers to reflect on how CT could be integrated into elementary science teaching. A key aspect was for the participants to collaboratively design CT-infused elementary science lessons as a culminating activity. Table 3 provides an outline of the seven sessions.

Participants

Participants in this study were MTs hosting preservice teachers as residents in their elementary classrooms. In total, 13 MTs enrolled in the workshops, and 11 continued to participate in the STIG^{CT}.[1] Participating MTs taught third through fifth grades and ranged in their years of teaching experience from 5 to over 30 years. All were female with diverse races/ethnicities (9 White, 2 African American, 1 Multiple Races (White, Hispanic/Latina), and 1 Asian American).

Data Collection

To gain insight into the ways in which participants saw the PD experience as influencing their ideas about CT, and because the IMPG suggests that reflection is a crucial element of growth, we offered ongoing opportunities for reflection. At the end of each session, participants were either asked to complete a written reflection on the day's activities or to engage in a discussion about how the activities had influenced their thinking about CT and CT integration. They were also asked to articulate emerging questions they had. At the end of the initial workshops and again at the end of the yearlong inquiry group experience, they engaged in small focus group discussions that solicited their ideas about CT, the benefits and challenges of CT integration in elementary science education, and their reflections on the experience.

Because we adopted the view that to bring about teacher change, outside PD (i.e., our MT workshops and the STIG^{CT}) must be combined with opportunities to try out and reflect upon new pedagogical practices in the classroom, we were also interested in how (or whether) teachers attempted to integrate CT into their science

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[1] We note that between the end of the workshops and the beginning of the inquiry group, several mentor teachers changed schools or positions, and were no longer serving as mentors to preservice teachers in their classrooms. However, these individuals elected to continue participating in the professional development experience.

Table 1 Overview of workshop 1 activities

Activity	Description
Preassessments	Participants completed an online survey related to their ideas about CT and CT integration. They were also asked to complete a drawing in response to the prompt, "Draw your students engaged in computational thinking while learning science."
Introduction to CT and CT integration	Participants viewed a video clip from code.org modeling CT integration in an elementary classroom and were introduced to CT as a Core Science and Engineering Practice in the NGSS.
Small group exploration of CT practices for math and science classrooms	Groups presented posters on four CT practices (data practices, modeling and simulation practices, computational problem-solving practices, and systems thinking practices (Weintrop et al. 2016)) and initial ideas about what they could look like in an elementary science classroom.
CT challenges using LEGO Mindstorms	Participants gained experience using computational thinking by completing a series of challenges in which they programmed robots to accomplish given tasks. Participants reflected on how they engaged in CT during the challenges, and what elementary student engagement in CT might look like.
Reflection	Participants reflected in writing on how the workshop's activities had influenced their thinking about CT and CT integration in elementary science.

instruction with elementary students. Therefore, we asked teachers to complete an online questionnaire at the end of the academic year following their participation in the STIG^{CT}. The questionnaire asked participants to state whether or not they had integrated CT into their instruction and how they had done so (or why they had not).

Data Analysis

We analyzed data using qualitative coding methods (Saldaña 2013). In our first round of coding, the research team inductively coded all data sources (written reflections, focus group interviews, and online questionnaire) to generate themes related to teachers' views on integrating CT into elementary science classrooms. We developed the following themes: strategies, tools/activities, student affect, challenges to student thinking, teacher affect, CT understanding, and professional support and constraints. These themes were cross-checked and coordinated by two researchers and triangulated across different data sources (written reflections, focus group interviews) in order to maintain validity. These themes were then applied in a second deductive coding phase using the IMPG model as a lens for interpreting our data. For example, the domain of practice, or pedagogies related to CT, included strategies, tools/activities, and innovation. The domain of consequence, or student outcomes resulting from CT-infused instruction, included components of student affect and challenges to student thinking. The personal domain—or the teacher knowledge, beliefs, and attitudes about integrating CT practices—included teacher affect, CT understanding, and components of professional support and constraints that were related to the teachers' belief system. The change environment included all other elements of professional support and constraints. After conducting this qualitative analysis for all participants, we selected three representative cases that illustrate a diversity of MT perspectives and experiences.

Table 2 Overview of workshop 2 activities

Activity	Description
Understandings of CT	Reflecting on their experiences from the previous workshop (6 weeks prior) and new ideas since the workshop, participants discussed their current understandings of CT.
Small group exploration of robotics tools for early learners	Participants engaged with KIBO (Kinderlab robotics) and Fisher-Price Think & Learn Code-a-Pillar, discussing how to cultivate CT in early elementary learners.
Integrating CT into elementary science through citizen science	Participants explored two citizen science websites: Celebrate Urban Birds (celebrateurbanbirds.org) and eBird (ebird.org). They practiced identifying birds outside with the Merlin Bird ID app, a technology tool to support student engagement with these citizen science initiatives. They then discussed the CT practices (Weintrop et al. 2016) that could be cultivated for students through citizen science engagement.
Reflection	Participants reflected in writing and through focus group discussions on how the workshop's activities had influenced their thinking about CT and CT integration in elementary science.
Post-assessments	Participants completed an online survey related to their ideas about CT and CT integration. They were also asked to complete a drawing in response to the prompt, "Draw your students engaged in computational thinking while learning science."

Table 3 Overview of after-school inquiry group session activities

Focus	Description
Session 1: Algorithms and procedures	Participants completed a self-assessment of their understanding of select CT concepts, then focused on the concept of algorithms and procedures using an "unplugged" programming activity.
Session 2: Problem decomposition and parallel processing	Participants explored the concepts of problem decomposition and parallel processing by working in small groups to simultaneously sequence segments of a story.
Session 3: Systems thinking	Participants rotated through four stations focused on aspects of systems thinking and discussed how systems thinking could apply to their elementary science curricula.
Session 4: Models and simulations	Participants explored three online simulations designed to support the teaching of elementary science topics. They discussed affordances and limitations of these tools.
Session 5: CT-infused science lesson planning	Participants worked in small groups to design elementary science lesson plans that integrated CT.
Sessions 6 and 7: Lesson presentations	Groups of participants presented their CT-infused lessons and engaged in reflective discussion in which they identified the lessons' CT practices and provided rationale for how the CT integration supported instructional goals in elementary science.

Results

We found that the process for change in teacher practice of incorporating CT into the elementary classroom is multifaceted and complex, as would be expected from Clarke and Hollingsworth's (2002) model. In this section, we first introduce our overall findings of change within the individual Domains of Practice, Personal, and Consequence (Clarke and Hollingsworth 2002), as stimulated by the experiences from the PD experience (the External Domain), described above. We then discuss the Change Environment—in this case, the teachers' school and school system contexts—that impacted the potential for change for these teachers. Finally, we conclude with three case studies of individual teachers to illustrate the overall findings and interconnections between the domains and the change environment.

Domain of Practice

We found that MTs were excited to incorporate CT into their practice, even searching out solutions to real issues in so doing. Some teachers integrated the CT activities that we had modeled in the workshops. Other teachers reported infusing aspects of CT, such as data collection, into everyday science instruction. However, in some cases, it was difficult to decipher whether teachers confounded general science and engineering pedagogy (e.g., engineering design, scientific inquiry) with the CT practices in Weintrop et al.'s taxonomy (2016). In these cases, while teachers identified specific activities as engaging children in CT, our analysis concluded that there was no computational aspect to the practices described.

Domain of Consequence

For this domain, our findings indicated that teachers found that CT was engaging to students and involved them in problem-solving. Teachers reported that CT-infused activities (e.g., robots, citizen science) had the potential to be motivating, interesting, and relatable for students because CT-infused activities deviated from typical school science in a way that was more engaging for students. Teachers also observed that CT encouraged students to solve problems by troubleshooting and thinking creatively. However, some MTs also suggested that some students may struggle with the higher-level thinking they saw as required to engage in CT. These MTs recognized the challenge of providing all students the necessary support as they problem-solve during CT activities.

Personal Domain

We discovered that, after participating in the workshops, teachers believed that CT practices offered an opportunity to use science teaching best practices. These included encouraging student collaboration; facilitating student discourse; engaging in problem-solving, inquiry-based and hands-on learning; and making real world and interdisciplinary connections. Many teachers believed that hands-on, student-centered activities, such as the CT-infused learning activities modeled in the workshops, increased accessibility to learners with different experiences and background knowledge. CT-infused activities provided teachers with opportunities to integrate technology in new and meaningful ways. Teachers also believed that engaging in CT helped students develop important life skills, such as problem-solving and critical thinking, essential practices for outside of the classroom. Teachers believed that student engagement in CT had potential benefits for students both within and beyond the classroom.

The Change Environment

We saw several key aspects of the change environment (Clarke and Hollingsworth 2002) that appeared to influence teachers' ideas and practices related to CT integration. For example, MTs perceived obstacles and supports related to science curriculum changes (at the national and local level), the resources available to them, and the priorities of their schools and districts.

Curriculum The districts in which the participating teachers worked adopted the NGSS in 2013 with full implementation (K-12) planned for the 2017–2018 school year. Thus, participants had experienced a recent change in local curriculum to align with NGSS, which included CT practices. However, NGSS K-5 standards only include CT in grade 5 in relation to mathematics (graphing). Therefore, while teachers found support with CT being explicit in NGSS, the standards did not provide guidance for them on how or where to integrate CT into elementary science. Additionally, some teachers viewed the local curriculum as limiting because it did not allow teachers to design their own CT activities.

Systemic Priorities Through our conversations with MTs, we found evidence of teachers' perceptions of systemic barriers as challenges to integrating CT in their classrooms. The MTs saw their school systems as placing greater instructional focus on reading and math, and limited focus on science. This focus on reading and math was reflected in the instructional time dedicated to those subjects, and several MTs explained that they had very limited time to teach science. This challenge may be compounded because MTs saw CT-infused science teaching as requiring even more time for students to engage in trial and error and complex problem-solving. Teachers also feared that administrators evaluating them would not understand the structure and management of a CT-infused lesson.

Despite the challenges, teachers were also optimistic that they could find coherence of CT with the school system's priorities. Teachers planned lessons that could be split across several days to manage the limited instructional time, and suggested integrating CT into other higher priority subject areas, such as math, for complex, real world applications. This may suggest that, in agreement with Yadav et al.'s (2011) findings, engaging in professional learning that emphasized the integration of CT into disciplines outside of computer science (i.e., disciplines that were already part of teachers' instructional responsibilities) helped to improve their understanding of how they could integrate CT into their practice.

Resources Teachers felt that several resources were necessary in order to effectively integrate CT into their practice. First, teachers needed *time*: planning time to find and modify CT activities relevant to the topics in their curriculum and instructional time to carry out longer CT-infused activities where students work through challenging problems. Second, teachers saw a need for *funds* to purchase materials to support CT integration in their classrooms. They perceived CT-infused instruction as requiring resources that may not already be readily available to them, such as technological tools. Some teachers successfully pursued individual grants to purchase technological tools for their classrooms. However, we did not interpret this approach as viable for all participants, or as a strategy likely to support exposure to CT for all. Third, teachers wanted more *practical examples* of activities they could use to incorporate CT into elementary science, especially using technologies already available to them or examples of activities that do not rely on technological tools (unplugged).

Mentor Teacher Case Studies

In each of the following case studies of participating MTs, we detail the areas of the IMPG in which the teacher experienced growth or was resistant to change. We identify initial change (if any) at the end of the mentor-only workshops, and then longer term change at the end of the entire PD experience.

Abigail Abigail (all names used are pseudonyms) is a 38-year-old White female with over 10 years of teaching experience. During the CT PD experience, she was teaching 3rd grade. Initially, Abigail reported several ways that she enacted CT in her classroom practice following her participation in the initial PD workshops (Domain of Practice). She discussed integrating some of the modeled activities into her classroom. For example, after participating in the citizen science activities during the initial CT workshops, she sought out and implemented a citizen science activity in her classroom. At this point, she was primarily taking ideas from the workshops and applying them nearly directly into her practice, although her "searching" for a citizen science activity showed beginning initiative.

However, over the course of the year's activities with the STIG^{CT}, Abigail began to evolve into a CT-infused science teacher. When asked at the end specifically how she had incorporated CT into her teaching practice during the year, she highlighted her efforts to insert CT into content she already taught in science. She stated: "I've gone off on my own and tried to look up some lesson plans just to see… what ideas I could take away. And some of the lesson plans, just about growing a seed, I had no idea [before] of what computational thinking is a part of that." (Abigail, end-of-year focus group). She also described integrating CT into the guidance she gave students as they prepared for the county's required science fair. She felt that participating in the PD experience illuminated strategies to infuse CT practices in activities that she was already conducting in her classroom. She stated, "I started to be able to piece together… how I can insert computational thinking standards into my labs… It started to kind of come together." (Abigail, end-of-year focus group).

This "coming together" that Abigail described was in part fostered by the connection with her growth in the Personal

Domain. She described how her participation in the PD experience influenced her confidence, and in turn, her teaching practice. She explained,

> …if I was reading some of the new science lessons we got this year, instead of glossing over things that I might've in the past, because science is a short time, I feel like I felt more confident. And so I made science longer and I really honed in on certain computational thinking skills. I felt more excited when I taught science. Maybe I just had a little more confidence because we're actually getting trained in something and learning something new, you know? (Abigail, end-of-year focus group interview).

In this excerpt, Abigail alluded to an issue in the change environment: "science is a short time" that has impacted her options for teaching science, not just CT-infused science. Her experiences both in the External Domain and in the Personal Domain have given her confidence to contend with this obstacle she sees in the Change Environment. However, while she attempted to overcome time constraints to teach science in the first place, there was another issue with Abigail's enactment of CT practices in instruction. The CT practices she refers to primarily relate to data collection (such as collecting data for citizen science projects, conducting science fair investigations, and measuring plant growth). While these data collection practices reflected valued science instruction that supports inquiry-based learning, they typically lacked a computational aspect. Except for collecting data for the citizen science project, all other data collection was done without a computational approach. Therefore, the PD may have transformed Abigail's science instruction to be inquiry-focused, but not necessarily to infuse CT in the way the research team presented it through Weintrop et al.'s taxonomy (Weintrop et al. 2016).

As more evidence of how her growth in the Personal Domain impacted her practice, Abigail highlighted her efforts to foster CT attitudes and dispositions (Barr and Stephenson 2011) while her students engaged in classroom-based lab activities. For example, she worked to support students in dealing with challenges or unknowns and encouraged them to communicate and work together toward common goals. Abigail saw CT as having helped students develop persistence and confidence as they worked with difficult problems (Domain of Consequence) which reinforced her change in practice.

> I think the children have to learn that there's many different solutions to a problem, and how complex problems can be. And through that trial and error… it develops some confidence with the children, especially with women and minorities, too, that they don't always get it right the first time. And it's something I think that, through my students this year, I saw now towards the end of the year. They're more confident in their labs. (Abigail, end-of-year focus group).

Abigail saw a benefit of CT integration in science as providing students with opportunities to manipulate and think about data in new ways, equipping them to use data to make decisions.

This relationship between the changes in the Domains of Consequence and Practice are further highlighted as Abigail discusses how CT integration could help develop foundational skills for elementary students that can provide them with new kinds of opportunities in the future. In the post-workshop focus group, she also saw a connection to equity:

> It's allowing our young children, especially our young girls, too. It's motivating me to motivate the girls in my class, besides just the boys, and really being able to give that to them so they know they can think along those same lines as an engineer and as a programmer, and it's not such a boys', you know, kind of job.

Abigail believed that CT integration helped her to make science and engineering more accessible for all students and "real world" for her students, supporting the CT for all venture.

Thus, in Abigail's case, we see the following connections. She uses the reflection time in the PD (External Domain) to think about her practice and her beliefs. These, her beliefs and practice, in turn, impact each other and are reinforced by the changes she sees in her students ("more confident"). Thus, as she enacted this new approach to teaching science and reflects on her learning and the outcomes, she projects a motivation to continue this transformation of her practice (see Fig. 2). The importance of the time in the PD for Abigail should be highlighted. At the end of the first two mentor-only sessions, she enacted the strategies taught to her, but did not incorporate them into her own beliefs or her practice. After the inquiry group, where she had time to practice, design lessons, and reflect, she began to show ownership over the ideas and used the changes in her students as a way to justify this change.

May May is a 25-year-old Asian American female. She was in her fifth year of teaching grade 4 during the PD experience. After participating in the initial workshops, May saw an opportunity to include CT practices in long-term projects her students completed at the end of the school year (Domain of Practice). She stated, "We do inquiry projects, and I feel like this [CT-integrated instruction] is a very interesting and more unique way of doing an inquiry project." (May, focus group interview). While May felt prepared to engage her students in

CT through these inquiry projects, there is evidence that she seemed unsure about how to infuse CT in the everyday science lessons the students engaged in given local school concerns (Change Environment). She left the first workshop asking the question, "With the [local school district] curriculum, how can we best incorporate it?" (May, written reflection). This issue seemed to have been resolved by the district the following school year: concurrent with her participation in the STIG^{CT} sessions, the curriculum at May's school had changed to align with NGSS standards. She explained, "our science curriculum this year… [is] embedding computational thinking." So, while May did not come up with a solution to the obstacle in the Change Environment, the obstacle's removal facilitated May's enactment.

After her participation in the STIG^{CT}, May described CT as "something that we already do without realizing it, but kind of putting a name to it." Her application of CT into instruction focused on data collection, similarly to Abigail's. She explained that CT is, "Data… collecting their own data so it makes sense and understanding the process" (focus group interview transcript). She gave an example of a CT-infused activity from her curriculum in which students developed physical models of water collection devices to collect rainwater. They reflected and iterated on the design of the water collection device based on how much water it collected (Domain of Practice). The curriculum shift coinciding with her participation in the after-school workshops changed her concerns about the accessibility of CT during science instruction. However, like in Abigail's case, it is unclear if and how the rain water collection design challenge engaged students in computational problem-solving. It is possible that Abigail and May both conflate science and engineering practices with CT (see the "Discussion" section for elaboration).

May described the CT activities infused into her teaching positively as student-driven and connected to the real world (Personal Domain). She explained in her focus group interview,

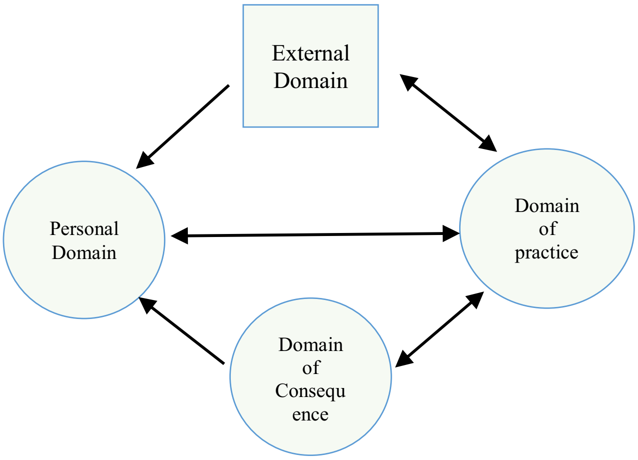

Fig. 2 Illustration of the relevant domains and reflection to Abigail's change

> [Infusing CT practices] makes it more authentic. So they realize that, in the real world, this is how problems are solved. I feel like the way science was taught was, you take a lot of facts and you have to memorize it but not understand the connection between them. But it's kind of what scientists do every day, is they have a problem that they work towards finding a solution. But also understanding the importance of it.

May believed that CT-infused activities deviated from typical school science in a way that was more engaging for students (Domain of Consequence). She also noted that these activities engaged students in a "productive struggle and showing that effort, motivation, and persistence …Those challenges, that's where the real learning occurs." She expressed that CT activities were genuine learning activities for children because there was no correct, obvious answer (Domain of Consequence). However, she indicated that these types of activities took a lot of instructional time, and it was challenging to find the time to complete them due to a districtwide focus on math and reading, indicating a restraint of the change environment. She explained her instruction is "so reading and math heavy that science is literally pushed to the side." In a follow-up interview, she stated that a major challenge to integrating CT was the time it takes to complete CT activities, and there is very limited time to teach science in the school day.

In summary, May was unable to enact CT in her classroom until she felt supported by the curriculum resources at her school. Originally, she had planned to only enact CT practices during the inquiry projects outside of the curriculum. However, the modified curriculum (Change Environment) in combination with reflecting on experiences in the STIG^{CT} (External Domain) allowed her to incorporate elements of CT into her practice, thereafter experiencing positive student consequences (Fig. 3). Still, other aspects of the change environment, such as time and prioritized math and reading instruction, prevented her from enacting CT practices to the extent that she would like. Unlike Abigail, however, it is unclear if May's participation actually influenced her beliefs of what students could do or the importance of CT in the curriculum. Thus, the connections in Fig. 3 look a bit different for her.

Janet Janet is a 50-year-old White female in her twenty-seventh year of teaching. During this study, she was teaching grade 5. Following participation in the initial workshops, Janet was eager and enthusiastic to introduce CT activities in her classroom. After using the LEGO Mindstorm robots in the first PD workshop, she said, "I literally walked out of here, and said, "Okay, we're getting some." Despite having no funds available at her school, Janet was able to obtain LEGO Mindstorm robot kits (~ $400) for her classroom by setting up a Donors Choose page (donorschoose.org), so that she could enact the activities from the workshops in her practice (Domain of Practice). In a focus group interview, her colleague explained, "So Janet made a Donors Choose page, and I was going to make one too but hers got fully funded for two Mindstorm kits" (5th grade teacher Erin, focus group interview transcript). The teachers went on to discuss how they would plan a lesson with the kits in their classrooms. Implicit in this "success" story was Janet's view that her school did not have the resources to support this change in practice. However, through experience and persistence, Janet was able to overcome that obstacle.

Janet's motivation to enact the CT activities was in part prompted by her belief that CT practices offered an opportunity to use science teaching best practices (Personal Domain). These included encouraging student collaboration; facilitating student discourse; engaging in problem-solving, inquiry-based and hands-on learning; and making real world and interdisciplinary connections. She explained,

> I think the collaboration piece is really important. Because we collaborate in a lot of different subject areas, but I feel like, for science, kids have different backgrounds and starting points. A lot of times somebody might offer an idea that someone else might not have thought of. But then once that has been put on the table, all of a sudden they can make a connection (focus group interview transcript).

However, Janet's beliefs were initially mixed. While she perceived benefits for her students and believed that CT could promote good science education for all, she also felt that she may need to help students troubleshoot more than she would be able during her robot lesson (Personal Domain).

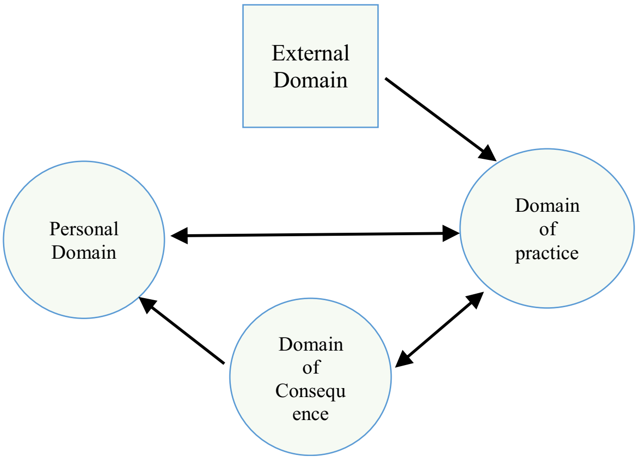

Fig. 3 Illustration of the relevant domains and reflection to May's change

> Now the struggle is, how do I introduce this to my group of 28 kids? Do I pull small groups at recess? I'm trying to figure out what my next steps are going to be. Because its overwhelming to me … I had to buy a book to figure, step by step, how to figure it all out. So I've gotten it part way, but it comes with a million pieces and I'm just thinking those pieces are going to be everywhere. (Janet, focus group interview).

Even after obtaining expensive resources and conducting research, she struggled envisioning the logistics of managing an entire class of students through the activity. In this case, the enactment did not impact her beliefs as she reiterated this concern after she introduced the robots to her large class. It is difficult to tell from Janet's words if her beliefs are in fact confirmed by the results of the implementation (Domain of Consequence) or if her beliefs are overriding the results. As she explained in her focus group interview:

> There's not enough of me going around to supervise or just to help troubleshoot … our kids, they're just not independent enough with that. And they need an adult there to sort of facilitate…And I just feel like, in our big classes, it's really hard.

Because she felt that students were unable to receive necessary support to troubleshoot through the process of building the robots, Janet resolved to build the robots herself. Then, she planned to pull the students and instruct them on "just the basics" (focus group interview). Thus, her beliefs about what students could or could not do were impacting her enactment of the CT activities.

Janet also struggled with how to integrate CT with science. Janet suggested the possibility of "pulling small groups at recess" (Janet, focus group interview) to work with the robots, suggesting that CT-infused activities could become an add-on to her teaching rather than an integrated part of her NGSS-aligned science instruction. While this may in part be a reflection of Janet's understanding of CT and the science curriculum, or her desire to do CT in small groups, she saw it as a limitation of the curriculum.

After the STIG^{CT} sessions, Janet expressed that she had provided other opportunities for her students to engage in CT in addition to the robots.

> In the fall we observed erosion problem areas around our school building and created water collection tools to collect then test the water. We also collaborated to develop solutions for the problems. In the winter/ spring we studied magnets created solutions for problems by

> engineering tools that used magnets. We investigated static electricity and discussed similarities with magnets. We used materials to create circuits in open-ended investigations. (Janet, end-of-year online survey)

It appears that Janet has overcome some of her concerns about what her students could or could not do without significant teacher support. However, it is unclear if she is confounding general science and engineering pedagogy (e.g., engineering design, open-ended investigations) with CT practices (teacher-identified as "data practices"), an issue we also observed with Abigail and May.

To summarize, we notice that after Janet participated in the first workshops, she enacted CT practices as something completely outside of the school science curriculum, something that required robots. Plus, she felt it was logistically challenging to support all students as they engaged in CT in her classroom due to the nature of the activity (constructing a robot) and the class size (28 kids). Thus, we see that the initial PD workshops prompted Janet's desire to change her practice (Domain of Practice) enough to motivate her to overcome obstacles from her school district (Change Environment), but the realities of implementing in a large classroom (Domain of Consequence) negatively impacted her beliefs and how she implemented CT (Personal Domain and Domain of Practice). However, with more time for reflection, planning, and implementing in the STIG^{CT} (External Domain), Janet described integrating CT-infused activities in the school science curricula (Domain of Practice). While she did not specifically discuss her beliefs, it is likely that they have begun to change to support the change in her practice. Reflecting on the activities in the STIG^{CT} may have given her a new perspective on how CT can be integrated in the classroom, changing her CT practices. Figure 4 shows the connections between the Domains for Janet, and we see a very similar pattern to Abigail's Domain Figure (see Fig. 2).

Discussion

In addressing our research question, *how did mentor teachers' views on integrating CT into their teaching practice change following their participation in a yearlong PD experience on CT?*, we found that teachers' views of CT developed across multiple dimensions. They communicated their own knowledge, beliefs, and attitudes about CT integration (Personal Domain), then they designed lessons which they perceived to integrate CT into instruction (Domain of Practice). Teachers were also able to describe outcomes of CT-infused learning for their students (Domain of Consequence). However, we found that participants struggled with how CT could best fit with their curriculum, how to champion CT in school environments unfamiliar with CT and that did not prioritize science instruction, and how to find the resources and support they needed to enact their ideas for CT integration (Change Environment). In this section, we synthesize across the case studies and general findings, looking for common themes that came out of the relationships between the Domains.

The Relationship Between CT and Science

We saw across the dataset that attempts to integrate CT into science practice stimulated science instruction and conversation, even while we questioned the computational relevance in the teacher designed CT-infused science activities.

Integrating CT into Science Instruction Deepens Science Learning The efforts to integrate CT into the classroom created a forum for teachers to focus on science instruction. While we were not always sure we saw CT in the lessons in the same way that the teachers did, the research team agreed that these lessons represented strong inquiry, student-centered lessons. In short, quality science lesson plans. Since elementary teachers typically struggle with creating scientific inquiry-based lessons, the fact that so many of the teachers designed and discussed this aspect seems to indicate a role for CT integration into science as promoting good science instruction. For example, Abigail (case study 1) indicated that the CT PD increased her confidence to create good science lessons, despite the constraints imposed on her. The PD community and teachers' eagerness to teach science with CT offered time, space, and support to discuss solutions to the school-related science constraints.

Further, our findings suggest that teachers grew to believe that computation can engage learners of all backgrounds, aligning with the goals of our project. The potential that teachers saw for CT to engage children who are not typically engaged with the science curriculum suggests that CT could help the mission of CT for All to spark early interest in science

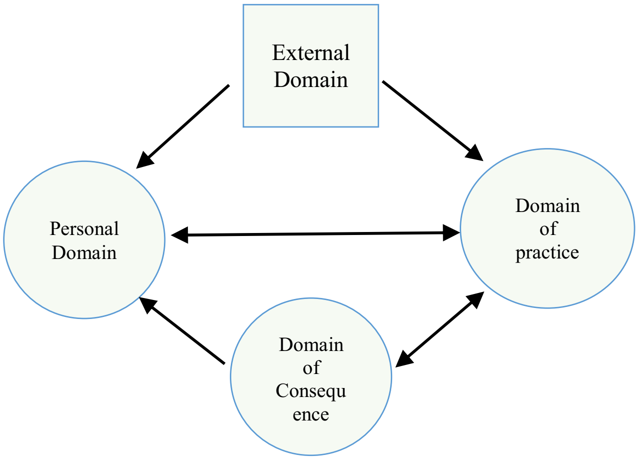

Fig. 4 Illustration of the relevant domains and reflection to Janet's change

and computation. While these claims may require further empirical investigation, the perspective of the teachers on the potential of CT is promising.

Conflation of CT Data Practices with Scientific Data Practices

In each of the case studies, the computational relevance of the activities the teachers described as integrating CT into their science instruction is unclear. For example, Abigail described her students engaging in CT when the students were growing a seed. This lesson asked students to record data about plant growth into charts, a valid and authentic science practice, but not necessarily an authentic CT practice. The same activity could have integrated CT more accurately if students had categorized or sorted this data to elicit patterns in it, demonstrating a computational approach to a problem. Similarly, May described a design challenge her students completed with a water collection device. From our perspective in this activity, students were engaging in engineering practices as they iteratively design features of their device to collect more water, not in CT. We would have liked to see students utilizing computational problem-solving, such as modeling the device on a computer prior to constructing the physical model, instead.

There are several factors that could have contributed to teachers identifying practices as CT in instances where the research team did not identify the presence of CT. First, CT integration in science may overload elementary teachers who typically lack confidence, experience, and knowledge about science (Shapiro 1996). Second, it is possible the limited time (and way) we presented CT practices to the teachers attributed to this confusion. Our use of Weintrop et al.'s (2016) taxonomy to define CT practices allowed teachers to identify common terms and apply them to familiar science practices. For example, teachers often identified "Data Practices" as any and all data collection and analysis (e.g., measure plant growth over time) in their lessons. However, the way teachers described these practices in their lessons did not reflect the way the research team conceptualized Weintrop et al.'s Data Practices—which involve a computational aspect to the collection of the data. Therefore, the practices the teachers attended to, while they were identified through the taxonomy's language, were often carried out in a non-computational way. Lastly, we wonder if presenting science and CT together may have blurred both topics so that novices to both did not fully identify the differences between them. As teachers provided reflections on how they implemented CT lessons over the course of the year, we became concerned about how an immature CT definition could play a role in claiming that a typical science lesson successfully integrates CT later. These findings suggest that longitudinal support is essential for teachers to enact and reflect upon CT practices in their instruction. We contend that researchers should continue to work to develop strategies to illuminate the complex, yet complementary, relationship between scientific inquiry and CT so that teachers are able to design meaningful CT-infused science lessons for their students.

CT Habits of Mind

Our findings indicated that teachers emphasized the disposition-building components of CT-infused activities (such as student engagement and problem-solving) as a critical component of student outcomes. For example, May highlighted the potential of CT to motivate and interest students by deviating from typical school science instruction. On the other hand, Janet suggested that some students may struggle with the higher-level thinking required to engage in CT. As teachers conceptualized CT-infused activities, they perceived providing all students the necessary supports as a challenge.

Our findings suggest that student attitudes and dispositions play a central role in the teachers' reflection and enactment of change. The field has struggled to determine the relationship between these dispositions the teachers described, and the definition of CT. Weintrop et al.'s (2016) taxonomy of CT practices for science and math as a framework excludes dispositions, whereas Barr and Stephenson (2011) posited student attitudes as a central tenet of engaging in CT. Even though we used the disposition-free Weintrop et al. framework, teachers provided unprompted reflections on the dispositions and attitudes that their students engaged in, showing that teachers noticed and valued those attitudinal changes. Therefore, the field should explicitly address the roles of student dispositions in CT when developing professional development or frameworks for practice to increase teacher efficacy.

Time Needed for Change

We saw a distinct difference between what MTs discussed at the end of the 2-day workshop versus after the STIG^{CT}. Initially, MTs typically copied what we modeled in the PD with little modification while sharing concerns over logistics and student capabilities. However, by the end of the STIG^{CT}, MTs all discussed how they integrated CT into their practice. The examples they gave were not ones that were modeled in the sessions; they came from participants' own professional understanding of their practice (including their knowledge of learning, curriculum, and pedagogical preferences). We identify these examples as ways that teachers were beginning to transform their practice to infuse CT into science (and for some even beyond science). They also discussed the value CT-infused science lessons had for their students and the attitudes those lessons fostered. Our study design does not allow us to conclude whether the change was due simply to increased time on task, or, as Clarke and Hollingsworth (2002) might agree, that the nature of the inquiry group helped foster that change. Clarke and Hollingsworth indicated that transformation does not come simply from change within the domains, but instead through reflection and enactment. Inquiry groups such as our STIG^{CT} are designed to promote reflection, discussion, design, practice, and post-practice reflection. Thus, the two key elements that Clarke and Hollingsworth promote are major elements in our STIG^{CT}. More research into this aspect is needed. Overall, we found in this study that the IMPG model of teacher change provided a useful lens for the interpretation of participants' views on integrating CT into their practice and helped to highlight the implications of our study for future work on teacher learning in the area of CT integration.

Conclusion

This study explored how teachers' beliefs and practices may change after participating in a PD experience designed to support elementary teachers infusing CT into their science instruction. The elementary teachers in this study were enthusiastic about integrating CT into their instruction and were able to do so with more integrity over time in the PD experience. We note several limitations of this study. First, the data collected is from teacher self-reports. Classroom observation data may triangulate and further validate or challenge the findings in this study. Second, although the workshops were open to first and second grade teachers, no MTs from these grades chose to participate. Future recruitment efforts may need to prioritize inclusion of early elementary grades to continue to support the CT for All position.

We see PD opportunities inciting change as catalysts to engage elementary-aged children in CT. Providing young children these opportunities to develop interest, foundational understandings in computation, and skills and practices that mirror those needed in the science workplace (data analysis, teamwork, problem-solving) has the potential to increase the number and diversity of students engaging in STEM and better prepare students for a career field with an increasing need for computational skills (Wing 2006). We posit that the results of this study highlight both the importance of including MTs in preservice teacher education around CT, as well as the need to reflect and practice in order to help teachers develop CT-infused science pedagogies. Although short-term trainings motivate teachers to integrate CT, our study indicates that continuous PD helps them change and transform their practice.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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