Professional Knowledge Building within an Elementary Teacher Professional Development Experience on Computational Thinking in Science Education

Abstract. We investigated teacher learning within a professional development (PD) workshop series on computational thinking (CT) for elementary-level mentor teachers. The purpose of the PD was to prepare mentor teachers to support preservice teachers in integrating CT into their classroom practice, toward the broader goal of advancing CT for all in the early grades. We examined the ways in which participants collaboratively built on existing professional knowledge as they engaged in professional learning activities designed to introduce CT and related pedagogies for elementary science education. Our data sources were field notes, artifacts, drawings, written reflections, and focus group interviews. We describe how participants developed new understandings of CT integration and made connections to existing professional knowledge of their students, their curriculum, and their school contexts. We discuss implications for teacher learning and PD design relevant to CT, and make recommendations for future research.

Introduction

Computational thinking (CT) is gaining traction as "a new literacy of the 21st century" (Wing, 2011, p. 22) and an ability that everyone, not just computer scientists, can benefit from developing (National Research Council, 2010; Wing, 2006). The National Research Council (2010) described CT as having comparable value to the mathematical, linguistic, and logical reasoning that all children are taught in school. Those calling for *CT for all* in K-12 education have suggested that engagement in CT can support the development of a new generation of creators and innovators (Lee, 2012); prepare and empower students to address pressing real-world problems (Barr & Stephenson, 2011; Lee, 2012); prepare students for careers in diverse fields that involve computing (Barr & Stephenson, 2011; Lee, 2012; NRC, 2010); foster collaboration, communication, and teamwork skills (Barr & Stephenson, 2011; Lee, 2012); and maintain and enhance the nation's economic competitiveness (NRC, 2010).

Members of the computer science and education communities have proposed a range of definitions for CT, and no single definition is widely agreed upon (National Research Council, 2010; Stephenson & Barr, 2012). Wing (2006) described CT as "solving problems, designing systems, and understanding human behavior by drawing on the concepts fundamental to computer science" (p. 33). A report from the National Research Council (2010) from a workshop on the scope and nature of CT outlined a variety of CT conceptualizations in the field, including CT as "procedural thinking" (p. 11), as "a way of formulating precise methods of doing things" (p. 11), and as "an open-ended and growing list of concepts that reflects the dynamic nature of technology and human learning" (p. 12). While the variety of perspectives on the nature of CT has generated interesting conversation in the field, it has also perpetuated a lack of clarity on what CT looks like in practice. This has complicated efforts to bring CT into K-12 education, and is problematic given the growing sentiment that college, where many students are first exposed to computer science and CT, is already too late (Barr & Stephenson, 2011; Wing, 2006).

With the goal of increasing exposure to CT for all students, beginning in the early grades, we have incorporated CT into Elementary Science Methods coursework for preservice teachers. Through these efforts, we have encouraged undergraduate preservice teachers to infuse CT into the lessons they teach in their field-based internship sites (1st-5th grade classrooms). During our pilot work, we observed that while preservice teachers in our courses responded positively to learning about CT, they were hesitant to innovate instruction in their field-based classroom internships to include it. We learned that some of this hesitancy was rooted in a perception that their mentor teachers at the internship sites were unfamiliar with CT, and may not view it as feasible to incorporate. However, in states like Maryland that has adopted the Next Generation Science Standards, CT is a practice that all students are expected to develop through their school-based science learning experiences. Therefore, it should also be familiar to teachers of science. We posited that involving mentor teachers in professional learning around CT could serve two important purposes. First, it could help mentor teachers themselves develop new understandings of CT and pedagogies for incorporating CT into elementary science teaching. Second, CT-knowledgeable mentor teachers could serve to provide preservice teachers with continuity of support for CT integration from the university context to their elementary classroom internships. Toward this end, we offered a series of professional development (PD) workshops for mentor teachers that mirrored what preservice teachers were learning in their Elementary Science Methods course about CT.

In this study, we investigated mentor teachers' experiences in these PD workshops on CT by examining the question: *How and in what ways did mentor teachers' engagement in PD workshops on CT enable them to build upon existing professional knowledge to support the inclusion of CT in their elementary science teaching practice?* We describe the design of the PD workshops, the kinds of professional knowledge participants brought to the workshops, how participants connected the ideas introduced in the workshop to their existing professional knowledge, and how these insights informed our thinking on future PD efforts and research in the area of CT and teacher learning.

Background Literature

Computational Thinking in K-12 STEM Education

To facilitate its inclusion in K-12 education, computer science educators and educational researchers have undertaken the work of framing and operationalizing CT for K-12 educators. Barr and Stephenson (2011) described a collaborative effort to develop an operational definition of CT that would be useful for this audience. Ultimately, they defined CT as a problem-solving process that includes a set of core concepts and capabilities (e.g., problem decomposition, abstraction, and automation), which are supported by a set of dispositions and attitudes (e.g., confidence in dealing with complexity, persistence with difficult problems) (Barr & Stephenson;

CSTA & ISTE, 2011). With regard to integrating CT into science education, the NGSS (NGSS Lead States, 2013) describe science learners' engagement in CT as encompassing skills such as using strategies for organizing and searching data, creating algorithms, and using and developing simulations of systems. Weintrop et al. (2016) offered a taxonomy for the inclusion of CT in school math and science consisting of four categories of CT practices. They suggested that in math and science classrooms, students can engage in CT through: 1) modeling and simulation practices (e.g., using computer-based simulations in a high school chemistry classroom to build conceptual understandings of the properties of gases); 2) data practices (e.g., creating and representing data from virtual experiments with gases under different pressure, temperature, and volume scenarios); 3) systems thinking practices (e.g., deriving gas laws by considering the system they have examined as a whole), and 4) computational problem solving practices (e.g., reflecting on the experience of exploring gas laws using computational models rather than traditional experiments) (Weintrop et al.). Weintrop et al. argued that embedding these practices in math and science education would help to model the reciprocal relationship between math and science and CT, support efforts to engage all students in CT, and align math and science education with current professional practices in these fields.

Advocates of introducing CT into K-12 education argue that beyond supporting students in developing new ways of thinking and problem solving, integrating CT into the existing K-12 curriculum (e.g., math and science education) has the potential to be instrumental in achieving the goal of CT for all. At present, students who take elective courses that involve computational topics do not typically reflect the diversity of the greater student body, with female and minority students being disproportionately underrepresented (Gallup Inc., & Google Inc., 2016; Orton, Weintrop, Beheshti, Horn, Jona, & Wilensky, 2016). Orton et al. found that embedding CT in required high school math and science coursework broadened exposure to CT for all students, positioned teachers to be successful since CT was situated alongside familiar content, and led to increased confidence and interest in computing and STEM careers amongst female students. Thus, integrating CT into the existing K-12 curriculum may present a promising strategy for increasing participation among diverse individuals in computing and STEM courses and careers.

Efforts to incorporate CT into K-12 education have been most prevalent on the secondary level, such as elective AP Computer Science courses in high school. Moves to include CT in the general education curriculum for all students, such as the *Using Mathematics and Computational Thinking* practice included in the NGSS, have been likewise most prevalent at secondary grade levels. This is evidenced by the fact that only two NGSS standards in the elementary grades (5-PS1-2, Matter and Its Interactions; 5-ESS2-2, Earth's Systems) explicitly incorporate the *Using Mathematics and Computational Thinking* practice, and only at the upper elementary (5^{th} grade) level. In addition, the integration of CT into elementary science education may also be impeded by limited instructional time devoted to science in the elementary grades (Blank, 2013). However, Angeli et al. (2016) noted that to be prepared to learn advanced topics in the later grades, students need to be introduced to CT at a young age. They presented a CT framework for grades K-6, and expressed the need for more investigation of CT teaching and learning at the elementary level.

Computational Thinking and Teacher Learning

To realize visions of CT integration into K-12 education, K-12 teachers need professional support (Yadav, Gretter, Good & McLean, 2017). Researchers have examined preservice and practicing teachers' existing notions of CT and related pedagogies, as well as the influence of various types of professional learning experiences on their thinking. In the absence of specific professional learning opportunities related to CT, several researchers have noted that preservice and practicing teachers may tend to view CT as the basic use of technology or computers (Bower & Falkner, 2015; Yadav et al., 2014). Accordingly, teachers may suggest the use of computers or technology as a pedagogical strategy that supports student engagement in CT (Bower & Falkner; Yadav et al.). Bower and Falkner also noted that when asked about pedagogies for supporting CT, teachers often provided examples of general pedagogical strategies (e.g., group work, scaffolding) that were not specific to CT development. Further, they found that teachers who were familiar with upcoming national curricular changes that included CT as a major component (i.e., the Australian Digital Technologies Curriculum), were not necessarily aware of CT. This finding might suggest that although many U.S. science teachers are aware of the NGSS, which includes CT as a core practice, it should not be assumed that they are specifically aware of CT or specific pedagogies to support CT engagement.

In our project, we seek to contribute to the literature on teacher learning around CT by examining the potential of engaging mentor teachers and preservice teachers in professional learning together. The short-term PD workshop we present in this study represents the initial phase of a yearlong professional learning experience in which mentor teachers will learn alongside preservice teachers. Professional learning experiences, even those that are short in duration, have shown promise for supporting teachers in developing more sophisticated conceptions of CT and related pedagogies. The National Research Council (2010) emphasized that such teacher education and professional development efforts should support teachers in developing the ability to model CT strategies for students, and guide them in learning to use these strategies on their own.

Given opportunities to learn about and engage in CT themselves, preservice and practicing teachers may be more likely to understand CT as a problem-solving process (Morreale et al., 2012; Yadav et al., 2011; Yadav et al., 2014). Additionally, after engaging in a CT module within a required teacher education course, Yadav and colleagues (Yadav et al., 2011; 2014) found that preservice teachers were more likely to use specific terminology when describing CT, see CT as possible *without* the use of a computer, and emphasize fundamental elements of CT (e.g., debugging, abstraction, algorithmic thinking). From a pedagogical standpoint, they found that following participation in the CT module, preservice teachers were more likely to see how CT could be used during problem-solving activities in their classrooms, recognize the role of CT across disciplines, and understand that CT could be integrated into the classroom even without the use of computers or technology (Yadav et al., 2011; Yadav et al., 2014). In another study within a preservice teacher education course, Jaipal-Jamani and Angeli (2017) found that a robotics intervention within the course yielded gains in preservice teachers' interest and self-efficacy to teach with robotics, as well as in their CT skills (e.g., writing algorithms, debugging programs).

Studies of teacher learning related to CT have offered a number of research recommendations. Historically, efforts to educate teachers about CT have been limited primarily to computer science teacher audiences (Yadav et al., 2014). To broaden exposure to CT among teachers, there is a need for CT professional support that reaches teachers of other content areas (Yadav et al., 2014; Yadav et al., 2017) and demonstrates the role of CT in disciplines outside of computer science (Barr & Stephenson, 2011; Jaipal-Jamani & Angeli, 2017). Mouza, Yang, Pan, Ozden, and Pollock (2017) called for studies investigating the development of TPACK-CT (technological pedagogical content knowledge in relation to CT) in specific content areas, particularly at the K-8 level. They described TPACK-CT as concerned with "teachers' ability to understand how CT-related concepts, computing tools, and practices (TK) can be combined with disciplinary content (CK) and pedagogical strategies (PK) to promote meaningful student outcomes in specific contexts" (p. 63), arguing that in order to incorporate CT into their teaching, preservice teachers would need to develop specialized knowledge of tools, vocabulary, practices, and dispositions. Yadav et al. (2011; 2014) suggested embedding CT into teaching methods courses as a promising approach, although they articulated the need for CT professional development efforts at the inservice teacher level as well, including within the primary grades. In general, there is a need for studies of effective professional learning approaches related to CT, including the most effective ways to structure these experiences (Bower & Falkner, 2015; Japial-Jamani & Angeli, 2017; Yadav et al, 2014). Additionally, there is a need for research that involves a variety of stakeholders for integrating CT into the K-12 curriculum, including educators, computer scientists, and policy makers (Yadav et al., 2014). Finally, the field needs follow-up research on how teachers incorporate CT practices into their own teaching following CT professional learning experiences (Yadav et al., 2014).

Theoretical Perspective

In considering how teachers learn during PD experiences, we adopted a socio-constructivist perspective on learning as a process of using existing knowledge to build new knowledge in community with others. Practicing teachers engage in ongoing learning "by living the practical experiments that occur as part of professional practice" (NRC, 2000, p. 191). Therefore, we were interested in how teachers' prior professional experiences informed their engagement with the new CT-related content, pedagogies, and tools introduced during the workshops. We were also drawn to the notion of collaborative knowledge-building among teachers within PD environments (Chai & Tan, 2009). Accordingly, in designing and facilitating the PD workshops on CT, we sought to create a space for teachers to engage in active learning while constructing new knowledge in community (Vygotsky, 1978).

Because the workshops represented the initial phase of a longer-term PD experience around CT for our participants, we were also interested in using our examination of teacher learning in the workshops to make adjustments to our PD design. To assist in this process, we examined research-based frameworks for designing and evaluating PD (Birman, Desimone, Porter, & Garet, 2000; Englebrecht & Ankiewicz, 2016). Englebrecht and Ankiewicz proposed criteria for evaluating continuing professional teacher development (CPTD) programs, suggesting that PD should take into account teachers' experience and prior knowledge. These should be used to further develop teachers' school knowledge; discipline knowledge; pedagogic knowledge; skills, attitudes, and values; and personal subject construct – while including theoretical, practical, and reflective experiences. Birman et al. identified six factors for effective professional development, including attention to form, duration, participation, content focus, active learning, and coherence. In examining how and in what ways teachers built on their existing professional knowledge through the PD workshops on CT, and considering these findings in light of research-based recommendations on PD design, we were able to identify areas for improvement or additional attention.

Methods

Since our goal was to provide preservice teachers with classroom support, our research team designed the mentor teacher workshops to parallel the instruction on CT that the elementary preservice teachers were receiving in the context of their science methods course (also taught by members of our research team). These mentor teacher learning experiences consisted of two

Saturday half-day PD workshops. The CT workshops (for mentor teachers) and the CT Elementary Science Methods class sessions (for preservice teachers) represent the initial phase of participants' professional learning around CT. Following these experiences, mentor teachers and preservice teachers will participate together in monthly afterschool PD sessions that extend their learning from this initial engagement with CT. In this study, we focus only on mentor teachers' experiences in the initial PD workshops.

Workshop 1. The first workshop provided mentor teachers with an introduction to CT (concept and defintion) and firsthand experience engaging in CT. Participants were introduced to the presence of CT in the NGSS, and the notion of CT integration in science instruction. To see an example of disciplinary integration of CT, participants viewed a video clip that showed elementary school students engaged in CT during math instruction through an "unplugged" activity that did not entail the use of educational technology. Connecting to the NGSS notion of practices, we introduced the idea of *CT practices* using Weintrop et al.'s (2016) four-part framework for CT in math and science education. Participants split into four groups, with each group examining one type of CT practice. Next, they worked in teams to complete a series of robotics challenges using LEGO MindStorms. After the activity, participants engaged in a large group reflection discussing the features of CT they learned by interacting with the robots, and what they thought children would learn from doing the activities. Finally, participants individually completed written reflections on their experiences throughout the day.

Workshop 2. The second workshop took place six weeks later. Participants began the day by engaging in a whole group discussion in which they shared their understandings of CT. Then, they built on the activities from the first workshop by engaging with robotics activities designed for early learners, using KIBO (KinderLab robotics) – a robotics toolkit for young children, and

Fisher-Price Think & Learn Code-a-Pillar—a commercial toy that teaches early programming skills. During the remainder of the session, participants focused on integrating CT into science instruction. We introduced citizen science as an approach that could offer opportunities to teach science content while promoting student engagement in CT. We defined citizen science as a form of public participation in scientific research that directly involves the public in the process of scientific investigation (Bonney et al., 2009), and as a field that has expanded in recent years with the public's increasing access to technology. Participants explored *Celebrate Urban Birds* (CUBs) and *eBird*, two citizen science initiatives from the Cornell Lab of Ornithology. They also practiced identifying birds using a mobile tool for citizen scientists, the Merlin Bird ID app. During the activities, participants were asked to identify CT practices being demonstrated. They examined connections between citizen science and the NGSS, including the NGSS Core Science and Engineering Practice of *Using Mathematics and Computational Thinking*. They were also introduced to the SciStarter website (www.scistarter.org) as a resource for locating grade-level appropriate citizen science opportunities. Participants then engaged in a whole group discussion about how citizen science could help teach curricular content in science while integrating CT. Last, they engaged in focus group discussions and written reflections about their learning from the workshops.

Participants

Participants in this study were 13 mentor teachers, representing three public school systems in our state. Participants were 3rd – 5th grade teachers recruited with the help of our University's Professional Development School (PDS) Coordinators, who serve as liaisons between the public school systems and the University's teacher education program. The PDS coordinators distributed flyers to the mentor teachers paired with preservice teachers in our elementary education program, and – with the mentor teachers' permission - provided our research team with the email addresses of those who were interested in attending the voluntary workshops. All of the participants were female, and ranged in age from 25-54 years old. Participants ranged widely in their years of teaching experience; 5 participants had taught for 3-5 years; 4 participants had taught 10-12 years; and 4 participants had taught over 30 years.

We asked participants about where, if at all, they had previously learned about CT. Eight of the 13 participants stated they had not previously learned about CT. The other five participants indicated learning about CT in voluntary PD sessions, university-based teacher education courses, from colleagues, from their work as mentor teachers, from curriculum materials, and from personal research (e.g., books, websites). None of the participants indicated they had learned about CT through a mandatory PD session, from a school administrator, or from their school district's standards documents. We also asked participants why they chose to participate in this PD experience. Aside from general responses such as for their own professional growth, participants indicated a variety of reasons for participating. These included: gaining insight into the NGSS, learning to infuse technology into mathematics and science, finding new learning activities to use in the classroom, and gaining familiarity with STEM.

Data Collection and Analysis

We collected and examined a variety of qualitative data sources: self-generated drawings, written reflections, and focus group interviews. For insight into the existing professional knowledge the mentor teachers introduced into the workshops, we examined their pre-workshop drawings in response to the question: "Draw your students engaged in computational thinking during science. Write what you intended to communicate in your drawing." We also examined participants' written reflections, completed at the end of each workshop, in which they answered questions about whether and how the workshop activities had influenced their thinking. At the end of the workshop, we collected post-workshop drawings. In addition, we conducted focus group interviews by grade level, in which participants discussed their learning from the workshops and its potential applications to their teaching practice. The discussions were audiotaped and transcribed for analysis. Participants' written reflections, post-workshop drawings, and focus group interviews gave us insight into the extent to which participants built on their existing professional knowledge and incorporated new ideas about CT and related pedagogy into their thinking.

In analyzing our data, we first sought to identify the kinds of professional knowledge that participants brought to the workshops, which they called upon when considering the new CT ideas being introduced. While we could assume that the data collected early in the workshops (e.g., pre-workshop drawings) represented participants' existing professional knowledge, we were also cognizant that the knowledge participants brought to the workshops also informed what they communicated in their ongoing written reflections and in the end-of-workshop focus groups. Therefore, we coded each of our data sources with the question of existing professional knowledge in mind. Next, we analyzed the ways in which participants appeared to build on this knowledge with new ideas related to CT that were introduced during the workshops. We coded for connections that participants appeared to make – individually (in drawings, written reflections) and collectively (in focus groups) between 1) the areas of CT policy, theory, and pedagogy; and 2) the professional knowledge and experiences they brought to the workshops.

Limitations

We acknowledge several limitations of our study. First, we acknowledge that we are reporting on a relatively short-term PD experience. Particularly because computational thinking was a new concept for the participating mentor teachers, the data we collected during the workshops represents participants' initial ideas on integrating computational thinking into their teaching. We believe that these ideas, as well as the nascent community of practice that was beginning to form within the workshops, could be further developed through longer-term PD participation. Future reports on this work will describe our ongoing engagement with these mentor teachers, along with their residents, in a Science Teaching Inquiry Group around computational thinking. Additionally, because our data collection took place at the beginning of, during, and immediately following the workshops, participants had limited time to try out and reflect on new pedagogical strategies they were bringing to their classrooms. Therefore, the benefits and challenges they described related to CT integration were primarily anticipated, rather than based on their personal experiences integrating CT into their teaching. Finally, we acknowledge that the participating mentor teachers were a self-selected group who participated voluntarily in PD workshops on computational thinking outside of their typical work schedule. Therefore, it may be the case that these teachers had a particularly high level of interest and motivation around the subject matter. Additionally, all of the participants taught in 3rd-5th grade classrooms. Therefore, our data are missing the voices of early grades elementary teachers. Had the workshops been required and the participants not self-selected, or had other elementary grade levels been represented (e.g., 1st and 2nd grade) amongst participants, it is possible that we would have observed results that would have supported, extended, or challenged our findings.

Findings

We begin by describing the existing professional knowledge participants contributed to the workshops, based upon their prior experiences as teachers of elementary science. Next, we describe how we interpreted participants' integration of CT concepts introduced in the workshops with their existing professional knowledge. We discuss how we interpreted these connections as having the potential to support or hinder participants' efforts to integrate CT into their teaching practice.

Existing professional knowledge

We interpreted elementary mentor teacher participants contributing to the workshops their unique professional knowledge in three key areas: 1) knowledge of their students; 2) their curriculum and their practical experiences teaching it; and 3) their school contexts. Elementary educator participants engaged in the CT-infused workshop activities with consideration of how the activities aligned with their understandings of how their students learn best, what their students would find motivating about CT, and how their students might struggle with CT.

Because they often described their students learning best through hands-on activities and active learning approaches, participants noted deficiencies in parts of their science curricula that did not lend themselves to such approaches. However, they described CT integration as potentially helpful for addressing this issue. Mentor teachers were also knowledgeable about the content within their science curricula and accompanying activities typically used to teach the content. This specific knowledge gave them a basis for considering how CT might fit with what they already do in the classroom.

Finally, mentor teachers also demonstrated their unique knowledge of their school contexts. A common theme in participants' discussions of CT integration in science was the challenge of finding time to teach science within the structure of their school day (Blank, 2013). Thus, integrating CT into science added an additional dimension to the existing challenge of teaching science at all. Another aspect of school context that participants described was the availability (or lack) of educational technology in their schools. For example, many participants felt the robotics activities modeled in the workshops would be appealing to their students, but logistically challenging in their school contexts due to lack of funds to purchase the equipment. Finally, mentor teachers expressed unique knowledge of their school communities, which shaped their ideas about how CT integration might be received. In general, they saw CT as unfamiliar to their colleagues, administrators, and students. While they saw it as possible to get the buy-in of these groups, they believed it would have to be introduced appropriately.

Connections between new content and existing professional knowledge

In analyzing our data, we identified three key areas in which we interpreted participants making connections between their existing professional knowledge and the content introduced during the workshops, signaling potential changes in participants' thinking about their teaching. These included potential changes in participants' thinking about: 1) policies impacting CT integration; 2) theoretical knowledge of CT and CT integration; and 3) pedagogies for CT integration. Within these areas, we also identified instances in which such connections between new and existing knowledge were less evident, signaling a possible need for us to adapt certain aspects of our PD approach.

Policies impacting CT integration. Following their participation in the workshops, we noted evidence of changes in the ways participants combined new knowledge of CT - and education policies impacting CT integration - with their existing knowledge of their school/district and curricular contexts. For example, one participant connected new understandings of CT with her existing understandings of District policy priorities and assessments. She described her experience in a District-sponsored math PD session, explaining,

> They want [students] to have… a productive struggle. Throw them a real-world problem that's very complex… [and ask them] 'What are the different ways you can solve this?'.

> And so the computational thinking is definitely being brought into the math curriculum, and I think principals are seeing the importance of that productive struggle now. So you've just got to turn it over to science as well. (Eva, 5th grade teacher, focus group interview)

In addition, we noted instances in which participants began to make connections with existing professional knowledge of their science curricula. Working in a state in which science curricula were informed by the NGSS, all participants indicated that they were familiar with the NGSS prior to their engagement in the workshops. However, nearly all stated that they had not previously learned about CT – despite its inclusion in the NGSS. Having received an introduction to CT in the context of the NGSS during the workshops, some participants began to consider how policy decisions – such as standards adoption – might play out within their curricula contexts and impact attention to CT. For example, one mentor teacher spoke about concepts like CT being "shoved aside because of Common Core" (Pam, 4th grade teacher, focus group interview), but now gaining new salience because of the adoption of the NGSS. Therefore, she believed it would be easier to integrate CT into instruction with the support of standards.

In these examples, we interpreted participants making connections between the CT content introduced during the workshops and their existing professional knowledge of their school and curricular contexts. In general, we viewed these connections as potentially productive for assisting participants in integrating CT into their practice. However, there were several instances in which participants connected the workshop content with their existing professional knowledge in ways that we interpreted as posing potential barriers to their efforts to integrate CT into their teaching practice. For example, with their familiarity with the language of standards, multiple participants began to talk about Weintrop et al.'s (2016) framework as a set of “standards” they were responsible to teach. While we see it as promising that a framework for thinking about CT could aid teachers in incorporating CT into their instruction, we are also cognizant that teachers have numerous sets of instructional standards to consider, and are cautious about the possibility that their interpretation of the CT framework as yet another set of standards could ultimately leave them feeling overburdened by the notion of CT integration.

Theoretical notions of CT and CT integration. The next category of connections we identified included instances in which participants’ showed evidence of new theoretical knowledge of CT and CT integration, that they were able to connect with existing professional knowledge of their students and their curricula.

By the end of the workshops, participants were able to talk about CT in terms of how it could support their students’ unique needs and interests. For example, having engaged in CT-infused activities, participants gained a sense of the kinds of dispositions CT could foster. They were then able to blend this understanding with their knowledge of their students. In describing how CT could help students in science, one participant explained: “[CT can help with] the persistence of following through. Because a lot of times, our kids, if they don’t get it right… they give up. ‘I can’t do it.’…This will get them to just keep trying with it. ‘Try this.’ That didn’t work? ‘I’m going to try this’. Troubleshooting.” (Ann, 5th grade teacher, focus group interview). In this instance, we noted the participant adopting the language of troubleshooting and describing the CT disposition of perseverance as beneficial to her students. In another example, we heard participants discuss CT as valuable for their students in terms of supporting their career preparation:

You’re building skills, and you have these new job opportunities: computer programmer

> or a designer. I think that's just opening [students'] eyes to a lot more career and college readiness opportunities… I think that it's allowing our young children, especially our girls to… know they can think along those same lines as an engineer and a programmer, and it's not such a boys' kind of a job. [Rita, 3rd grade teacher, focus group interview]

Such examples suggested that participants were blending existing knowledge of their students with new knowledge of CT and CT integration.

Participants also showed evidence of combining their existing knowledge of curriculum and pedagogy with new knowledge of CT. We noted examples in which participants, following their engagement in the workshops, began talking about science in new ways (e.g., with a problem-solving focus). In addition, some participants began using the language of practices. For example, in her post-workshop drawing (see Figure 1), one teacher explained that she sought to show: "Students working through the various practices using the LEGO robots from the initial build to the finished process." [Ann, post-workshop drawing]. We also noted evidence of participants' abilities to recognize how CT practices can be applied during science activities, such as the citizen science activity modeled during the workshop. Following the workshop, one participant described,

> You have to try and find [science learning activities] that encompass more than just one kind of practice. I think [I'm] really just seeing the computational thinking in multiple areas. Whereas before, I didn't really know what it was. I wasn't really understanding how it can be applied into the science. (Jenny, 5th grade teacher, focus group interview)

We interpreted instances like these as potential evidence of participants connecting their existing knowledge of curriculum and pedagogy with new ideas about CT integration, potentially changing participants' ideas about their science teaching.

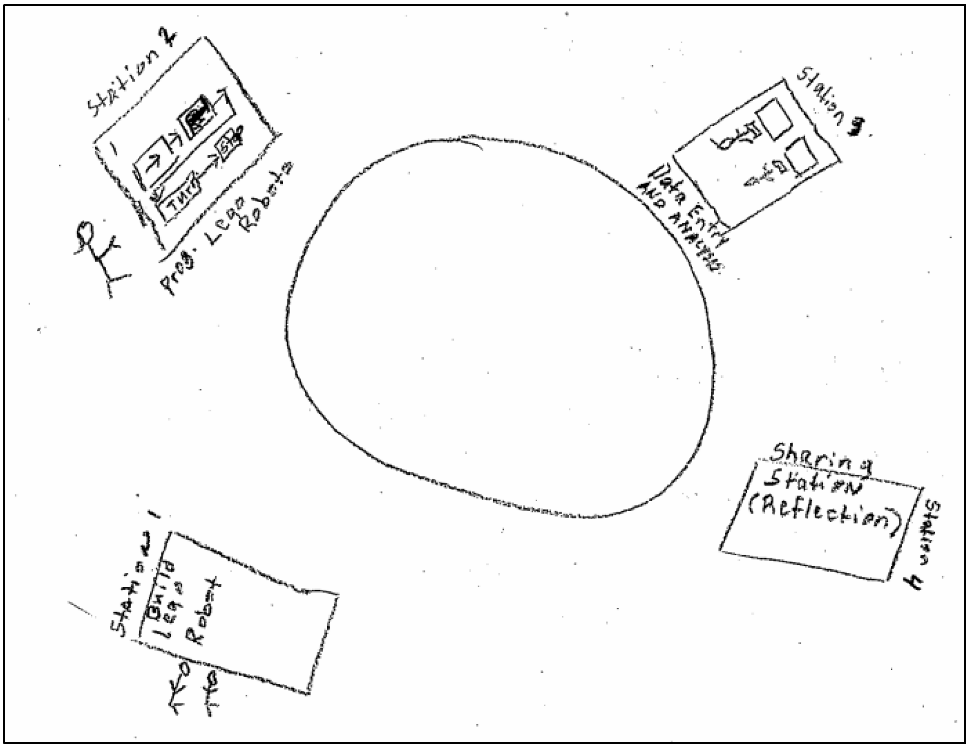

Figure 1. Mentor teacher Ann's post-workshop drawing in response to the prompt: "Draw your students engaged in computational thinking while learning science"

We also noted some examples, however, in which we were unsure whether the connections participants made between the workshop content and their existing professional knowledge would support their efforts to integrate CT into their science teaching. At times, we noted that participants began speaking about CT practices, but did not connect the notion to their own teaching practice. For example, one participant spoke about computational problem solving practices in terms of everyday problem-solving (e.g., fixing a broken pencil sharpener), but not specifically to teaching science. Or, as in Figure 1, some participants talked about CT in terms of the activities modeled in the workshops (e.g., robotics), but did not clearly describe how they would connect these ideas to their science curricula. We also noted multiple instances in which participants appeared to use the idea of CT as a catchall for any kind of challenging thinking that could be encouraged during science instruction (e.g., higher order thinking, critical thinking, analytical thinking). We were uncertain, without additional explanations provided by our participants, how they aligned their personal definitions of CT with the definitions of CT practices included in the Weintrop et al. (2016)'s taxonomy.

Pedagogies for CT integration. The final category of connections we identified were between participants' existing professional knowledge and their new knowledge of pedagogies for CT integration. At times, participants showed evidence of combining such knowledge with knowledge of their students. For example, in describing her experience with the robotics activities modeled in the workshops, one participant stated,

> I could see kids getting frustrated. And that would be a challenge. But I think as you expose younger kids to the importance to that STEM that's needed, and then "Let's try it a different way. Let's try it a different way. Let's try it a different way." And it's okay. You have to have that right mindset, too, that it's okay to fail. Because that's what helps you succeed. Kids don't have that mindset right now. (Eva, 5th grade teacher, focus group interview)

Here, the participant showed evidence of bringing in the notion of testing or troubleshooting as a computational problem-solving practice into her science teaching pedagogy, while remaining cognizant of how her students might feel about such a change in approach.

Participants also showed evidence of connecting new knowledge of pedagogies for CT integration with existing knowledge of their curriculum and their own teaching experiences. In a number of instances, participants described existing aspects of their instructional approaches in science, and emergent connections they saw with CT-infused pedagogy. For example, they suggested making changes to traditional science fair projects so that CT could be incorporated.

One example was evident in the following exchange during one of the post-workshop focus group interviews:

> Mary (4th grade teacher): …They encourage a science fair. And I'm like, "Yeah, science fair, [but] let's do this new type of thinking"
>
> …
>
> Briana (4th grade teacher): I think a lot of times, when we do science fairs or things where we're collecting data, we have the kids collect data and [they] might answer a couple comprehension questions, but we don't really move past that. So I think that understanding that column [in the Weintrop et al., 2016 taxonomy] that's all about the systems part, that whole part we don't really touch on with kids.

In instances like this, participants generated ideas about how their existing curriculum and teaching practices could be adjusted to integrate CT – something we saw as potentially productive for improving their science teaching practice.

Additionally, however, we noted instances in which it was unclear whether participants considered making these types of adjustments. For example, in a written reflection, one participant stated that the workshops showed her "how much we already use computational thinking in science" (Dawn, 5th grade teacher, written reflection). In cases like these, while participants may be increasing their abilities to recognize where CT is relevant within their curricula, we were unclear whether the workshops made them think about their teaching in new ways. Similarly, there were many instances in which participants described CT as supporting the types of pedagogies they already understood as good teaching practice in science (e.g., hands-on, collaborative). We interpreted this phenomenon as a product of the types of activities modeled in the workshop, which included these characteristics. However, in such cases, we had difficulty interpreting whether the participants saw CT infused-teaching as something more than “good science teaching” or if they saw themselves changing anything about their science teaching practice in light of what they had learned in the workshops.

Lastly, we identified instances in which participants’ connected existing knowledge of their school contexts with new knowledge of pedagogies for CT integration. Participants entered the workshops already aware of the challenges of fitting science in during their school day, but also aware of how these challenges could be addressed. Many participants described, for example, how making interdisciplinary connections across the elementary curriculum afforded more opportunities for student engagement in science. Using the same reasoning, participants described strategies for fitting CT into their instruction. As one participant explained, “I feel like I can apply it, not just with science. This has given me a better scope of how I can apply it with reading, with health, with pretty much everything – every subject” (Briana, (4th grade teacher, focus group interview).

Participants also entered the workshops with knowledge of the educational technologies available within their school contexts, and how they are currently used. During the workshops, the facilitators modeled a variety of educational technologies while presenting CT-infused learning activities. Following the workshops, a number of participants began to talk about new ways to use available educational technologies to support CT-infused learning in their schools. For example, one teacher explained,

> As we were first having Chromebooks and computers in the classroom, it was like, "OK, well, type the story that you wrote and then play this game." And I've, it took me a few years, I think, to kind of branch out and think about new ways to integrate the technology that we have available. And then when you add in that computational thinking and how

> can you use the technology as a tool…. Like, look at all the different ways that we've been able to use technology just in the workshop… Now I have some new ideas. (Ellen, 4th grade teacher, focus group interview)

In cases like these, we interpreted the connection between participants' existing knowledge of their school contexts with new knowledge of pedagogies for CT integration as potentially productive for supporting participants in their efforts to bring CT into their science instruction.

However, there were also cases in which participants' knowledge of their school contexts made them question whether integrating CT would be feasible. Participants noted the lack of familiarity with CT within their schools, the fact that CT represented a new approach that would require some adjustment for students, or that time was limited for engaging in new ways of teaching and learning that involved CT. In such cases, we were not clear how participants would ultimately reconcile the challenges they identified, and whether the connection between new and existing professional knowledge might support CT infusion in elementary science education.

Discussion

In analyzing data from mentor teachers' engagement in PD workshops on CT, we found that participants made connections between existing professional knowledge (i.e., of their students, their curricula, and their school/district contexts) and new knowledge (i.e., of policies impacting CT, theoretical notions of CT and CT integration, and pedagogies for CT integration), which we interpreted as having the potential to support their efforts to bring CT into their teaching of elementary science.

We believe that certain characteristics of the PD experience afforded opportunities for the productive blending of new and existing knowledge for participants. First, by focusing in on a specific aspect of the NGSS – the inclusion of CT as a practice – participants gained a depth of understanding that may not have been possible in prior introductions to the NGSS that provided a general overview. In delving into detail about the nature of CT and what it might look like in the elementary classroom, participants could identify ways it could enhance student learning and align with school or District-level priorities. Second, with the introduction of a framework for understanding CT, participants were able to recognize how elements of CT were already present in their science instruction (although not prevously termed as examples of CT) – as well as places where new elements could be incorporated. Finally, by experiencing firsthand CT-integrated learning activities (i.e., robotics, citizen science), participants gained practical understandings of CT-infused instruction and were able to anticipate the potential benefits and challenges they might face in enacting such approaches. We believe that opportunities to engage and reflect with other elementary teachers in a nascent community of practice for CT integration also encouraged the exchange of ideas about how CT concepts were relevant to what participants already understood about their students, their curriculum, and their schools.

The decision to focus on CT integration specifically within science education during the workshop presented benefits and challenges. As Orton et al. (2016) described, embedding CT within required K-12 coursework has the potential to support broader exposure to CT among students and can position teachers to be successful by embedding CT in familiar content. These benefits may also translate to our study context. However, Orton's study took place at the high school level, in which teachers were specifically dedicated to teaching science (and math), rather than all subjects, as is the responsibility of the elementary mentor teachers in our study. Our participants were cognizant of a relative lack of attention to science, in comparison to other subjects like reading and math, at the elementary level. While they expressed concern about finding time to teach science, let alone CT-integrated science, they were also experienced in dealing with this challenge. With science as a typically subordinate subject, participants suggested interdisciplinary instruction as a way to increase the amount of instructional time that could be devoted to science (Blank, 2013), as well as a way to increase the amount of instructional time that could be spent integrating CT. Therefore, while a focus on CT integration in science helped to maintain a manageable scope in the workshop, it may be the case that encouraging interdisciplinary connections through CT may align well with the ways in which elementary educators manage their instructional time. Professional development that explores such possibilities may help to identify new ways to realistically respond to calls for CT integration in the early grades (e.g., Angeli et al., 2016).

Other PD design choices may have contributed to instances in which we were unsure whether the connections participants made between their existing and new professional knowledge would be likely to support their efforts to integrate CT into their science instruction. While the introduction of a framework for CT integration in science helped participants recognize elements of CT that were already present within their science instruction, there were instances in which participants interpreted these familiar elements as evidence that they were already integrating CT. We believe it is likely to be the case that many of the participants were already incorporating CT elements into their teaching, even without making an explicit effort to do so. However, we are also cautious about the possibility that interpreting CT as already present within their instruction could have the potential to dissuade participants from seeking to incorporate it in new or expanded ways.

In addition, while modeling CT-infused activities appropriate for elementary learners gave participants practical experience with pedagogies for integrating CT, there were many cases in which the participants considered *only* these activities as possibilities for integrating CT into their instruction. This was especially evident in the post-workshop drawings, in which nearly all participants drew their students engaged in robotics (e.g., Figure 1) or citizen science activities. It was rare for teachers to consider how CT concepts modeled in the PD activities could be extended to the learning activities they already do in their classrooms. Therefore, it may be useful for teachers to have opportunities to discuss how elements of activities presented during PD can translate to their curricula.

Using research-based frameworks for the design of effective teacher PD (Birman et al., 2000; Engelbrecht & Ankiewicz, 2016), along with our insights into teacher learning during the workshops, can shed light on necessary PD design adjustments as well as on areas for future research. For example, using Engelbrecht & Ankiewicz's CTPD criteria, our analysis suggested that teachers developed in their personal subject constructs (i.e., understanding of CT) and pedagogical knowledge. However, we know less about how or whether the PD experience developed teachers' school knowledge (e.g., resources available in their schools to support CT, support people at their schools with whom they could collaborate) or discipline knowledge (e.g., in Life Science, Physical Science, Engineering) (see also Birman et al.) Fortunately, because the workshops were designed to be a starting point for ongoing PD efforts with these mentor teachers, opportunity existed to extend the duration of the PD experience. We made the decision to facilitate monthly gatherings throughout the school year of a CT Science Teaching Inquiry Group for these mentor teachers, along with their preservice teacher residents (Hestness et al., 2018; Ketelhut et al., 2018; McGinnis et al, 2018), allowing our PD approach to take on additional features of reform-type PD activities (Birman et al., 2000).

Implications

This study has implications for future teacher education PD efforts related to CT integration and for future research. Our findings suggest that PD related to CT should place a special emphasis on clarifying for teachers the unique characteristics of CT, which are related to but also distinct from other types of challenging thinking in which students might engage. It should also support teachers in generating ideas about how to adapt CT concepts and strategies to align with their existing science teaching practice, and think beyond the limited selection of activities that can be modeled within a given PD experience. That is, just as teachers should be able to model CT strategies for students so they can learn to use them on their own (NRC, 2010), PD experiences must model CT strategies in ways that help teachers learn to use them on their own, while making appropriate adaptations for their own teaching situations. In terms of future research, we suggest there is a need for investigations that explore whether and how teachers with science teachig responsibilities integrate CT into their classroom practice following PD interventions, the affordances and challenges of integrating CT into their practices, and - for the mentor teacher population we studied - how they are able to support their mentee preservice teachers in integrating CT in science instruction. Such efforts could contribute to our understanding of how teacher learning related to CT can be most effectively translated to improving science teaching practice in ways that are responsive to the realities of teachers' school contexts.

Conclusions

We believe that identifying the ways in which teachers may connect existing professional knowledge with new knowledge around CT and CT integration represents a promising first step in expanding our understanding of how to foster mentor teachers' capacity to integrate CT into their elementary teaching practice, and moreover, their capacity to support preservice teachers in doing the same. In particular, we noted that mentor teachers were drawn to the ways in which CT could help their students think and problem solve in new ways, while developing perseverance in addressing challenges. Finally, we see potential benefits in fostering the development of a teachers' learning community in computational thinking through ongoing PD opportunities.

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