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Preservice Science Teachers' Beliefs About Computational Thinking Following a Curricular Module Within an Elementary Science Methods Course

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The authors describe their study of a curricular module on computational thinking (CT) implemented within an elementary science methods course and reported insights on preservice science teachers' (PSTs') beliefs about CT integration. The research question was, "Following participation in a curricular module on CT, what is the nature of PSTs' beliefs about CT integration in their elementary science classrooms?" The authors designed and implemented a three-class-session CT module within an undergraduate elementary science methods course. They observed and collected field notes on PSTs' (*N* = 39) participation in the module, along with class artifacts. They examined the data to gain insight into PSTs' perceptions of CT integration in elementary science education, its feasibility, and its value for their own teaching practice. They found that PSTs overwhelmingly supported the pedagogical innovation of integrating CT in their science teaching; they appreciated that CT modernized and made science education engaging for young learners; and, they generally believed that CT integration supported the implementation of what they understood as good science teaching practice. However, the PSTs believed they would face a variety of challenges in their efforts to integrate CT into their science teaching. Implications for CT teacher education are discussed.

As society becomes more interconnected with computational tools, the need is increasing for everyone to have computational skills, not only computer scientists (Wing, 2006). Toward this end, school systems need to integrate computational thinking (CT) into everyday teaching and learning for all students (Barr & Stephenson, 2011). Unfortunately, many schools are not prepared to do so. Instead, CT has been almost exclusively isolated in computer science elective coursework, with White and Asian males comprising the majority of the class populations (Orton et al., 2016).

Consequently, the computer science workforce reflects a gender and racial profile that does not represent the rich diversity in schools or in the broader workforce (Gallup Inc. & Google Inc., 2016). To introduce all students to CT, computational practices must be infused into core required coursework. Science is a natural connection for CT integration at all grade levels. Further, integrating CT into the science curriculum may engage children who are not typically engaged with the traditional science, technology, engineering, and mathematics (STEM) curriculum (e.g., through e-textiles; Jayathirtha & Kafai 2019).

For learners to develop interest and foundational understandings about CT, they need opportunities to engage in CT, particularly at a young age. Building students' CT interest and dispositions in elementary school has the potential to increase the number and diversity of students choosing to engage in CT in secondary school and beyond.

Elementary school teachers are, however, often insufficiently prepared to integrate CT into their science teaching practice. They may lack experience and knowledge about science and computer science. Because they teach a variety of subjects, they may not have the necessary coursework or experiences to support student learning in some topic areas and may require additional support in building knowledge of science content and scientific inquiry (Ma, 1999, Shapiro, 1996).

Recently, the *Next Generation Science Standards* (NGSS Lead States, 2013) specified eight scientific inquiry-related practices that included "Using Mathematics and CT." Similar to the historical trend of elementary science education, teachers at the elementary level also lack experience and understanding of CT (National Research Council, 2013). Therefore, without targeted support, they may struggle to incorporate CT in their classrooms (Bower & Falkner, 2015; Yadav, Mayfield, Zhou, Hambrusch, & Korb, 2014).

An additional challenge facing elementary science teachers is that effective practices for integrating CT into elementary science are currently undefined by standards or literature. Barr and Stephenson (2011) defined CT as a problem-solving process that includes a set of practices that are supported by a set of dispositions and attitudes (Computer Science Teachers Association [CSTA] & the International Society for Technology in Education [ISTE], 2011).

Weintrop et al. (2016) provided a taxonomy of CT practices for science and mathematics in secondary schools but did not indicate the applicability of the taxonomy to elementary science instruction. The Committee on STEM Education (2018) placed attention on students' need to develop "computational literacy" (p. 21), and the NGSS include "Using Mathematics and CT" as a practice. However, the NGSS do not explicitly include CT in elementary science. The practice is cited only in two standards in Grade 5, both of which utilize mathematical activities such as graphing. Therefore, the NGSS provide little explicit guidance for teachers on the application of CT in elementary science.

While this area of research remains relatively underexplored, a few researchers have conducted studies that investigated how to support teachers in integrating CT effectively into instruction (Bower & Falkner, 2015; Jaipal-Jamani & Angeli, 2017; Lambrou & Repenning, 2018; Yadav et al., 2014). Emerging findings show that teachers may tend initially to view CT as use of technology or computers (Bower & Falkner, 2015). From that perspective they may believe it will be logistically challenging to implement in elementary schools due to a lack of resources to purchase such equipment (Hestness, Ketelhut, McGinnis, & Plane, 2018). However, there is little research on teacher beliefs about integrating CT into their practice.

We sought to expand this understanding by investigating how to support elementary teachers in integrating CT into elementary science. In this study, we focused on exploring their beliefs about the value and feasibility of doing so.

Theoretical Perspective

Theoretical perspectives on teacher beliefs, particularly in relation to curricular reforms, informed our research. In their examination of teacher beliefs about scientific argumentation in the classroom, McNeill, Katsh-Singer, Gonzalez-Howard, and Loper (2016) found that teachers held varied beliefs about what counts as argumentation and suggested that these varied beliefs had the potential to impact whether and how they integrated argumentation in their classrooms.

Computational thinking may be fruitfully viewed as similar to argumentation, in that it represents a reform-based practice that teachers are increasingly responsible for implementing in their science classrooms. It may be interpreted — and thus, implemented — quite differently, however, depending on teacher beliefs.

Gregoire (2003) developed a theoretical model of the linkages between teacher beliefs and teachers' implementation of curricular reforms, the Cognitive-Affective Model of Conceptual Change (CAMCC). In this model, teachers may respond to a reform message in one of two ways: either with a perception of the reform as threatening (i.e., changing; which Gregoire termed a "stress appraisal") or supporting (i.e., maintaining; which Gregoire termed a "benign-positive appraisal") their current teaching practices.

Teachers who see the reform as threatening or requiring a change to the status quo in their classrooms, have the greatest potential for belief (and thus, instructional) change. Conversely, those who perceive the reform as supporting the status quo are more likely to accept the reform superficially without undergoing a true change.

Gregoire noted that motivational and affective factors, such as teachers' self-efficacy and perceptions of their teaching contexts (i.e., beliefs about the feasibility of implementing the reform) and perceptions of the importance of the reform (i.e., beliefs about the reform's value), intervene and play a role in determining the extent of teacher belief change (i.e., true conceptual change, superficial belief change, or no belief change). We drew on Gregoire's theoretical perspective on teacher belief change by examining participants' perceptions of the reform (integrating computational thinking into elementary science education) and then examining their views of its feasibility and value to gain insight into their beliefs about CT integration.

Literature Review

To effectively integrate CT into K-12 education teachers must be supported to infuse CT practices into their existing practice, particularly at the elementary level. Thus far, research exploring how to support teachers' integration of CT has primarily examined preservice teachers' ideas about (a) what CT is, (b) CT-related pedagogies, and (c) CT-related attitudes.

Both Bower and Falkner (2015) and Yadav et al. (2014) conducted surveys of preservice teacher understanding of what CT is. They found that novice participants were likely to conflate CT with general use of technology, rather than a problem-solving process. These results indicate that without explicit CT learning experiences teachers are unlikely to have a strong understanding of CT or how to integrate it into instruction.

Bower and Falkner (2015) asked preservice teachers about their concepts of CT-related pedagogies. They found that participants did not have a clear understanding of how pedagogical strategies (i.e. group work and scaffolding) could promote computational thinking. They also found that teachers generally lacked confidence to integrate computational thinking into their classrooms, because they lacked lesson ideas and examples of applications of CT to the real world.

Similarly, Yadav et al. (2014) found that preservice teachers who participated in a CT-module had significantly better attitudes about teaching CT than did their peers who had no CT instruction. These findings suggest that for teachers to develop the skills and confidence needed to integrate CT into their classrooms, they need explicit CT instruction, resources, and tools that help them to integrate general CT principles into everyday teaching and learning (See Cabrera, Ketelhut, Hestness, Mills, & McGinnis, 2019, and Garvin, Killen, Plane, & Weintrop, 2019, for literature reviews on teacher preconceptions of CT and on what CT is, respectively).

Absent from these previous research studies examining teachers' professional learning experiences about CT integration is any documentation of teachers' beliefs regarding the value or feasibility of doing so. Exploring how belief systems interact with professional development and classroom practice is an essential component of teacher change (Clarke & Hollingsworth, 2002).

Teachers could have a strong understanding of CT and how to teach it, but still not actually integrate CT into their practice, due to their perceptions about students' ability, school culture, curriculum, or time constraints. Further, previous findings from our study have indicated that some teachers believed they were integrating CT in authentic and relevant ways, but were more inclined to integrate scientific inquiry (data collection and investigations) than computational practices (computational devices and algorithms). (See Ketelhut et al., 2019.)

We investigated if and how preservice teachers believe CT could be integrated into their classroom practice after participating in a professional learning experience about CT in a science methods course. (Additional information on the project in which this study is embedded can be found in Hestness et al. (2018).

We were interested in whether preservice teachers viewed CT as something that was already embedded in their classroom or something that was completely separate from what they are doing in their classroom. Additionally, we explored how these beliefs intersected with their perceptions about the value and constraints around CT integration in elementary science.

Methods

Study Context

We conducted our study in the context of an undergraduate elementary science methods course at a large university in the Mid-Atlantic region of the US. A member of our research team (McGinnis) was the instructor. The purpose of the course was to prepare preservice elementary teachers (PSTs) to engage learners in grades 1-5 in the processes and concepts of science, as guided by the NGSS.

The course instructor McGinnis highlighted the NGSS Core Science and Engineering Practice of CT through the inclusion of a CT curricular module within the course. The course also introduced PSTs to a wide variety of pedagogical concepts related to STEM teaching and learning, policies impacting classroom science teaching practice, assessing student learning in science, promoting equity in the science classroom, and lifelong professional development in science education.

During the semester in which they were enrolled in the course, PSTs spent part of their time in field-based elementary classroom internships in professional development schools alongside mentor teachers. PSTs' performance in the course was assessed through their participation in class discussions; their written reflections on assigned readings; an assignment in which they developed a practice science lesson and taught it to a small group of peers in class; and a major final assignment in which they developed a standards-based science lesson and taught it to elementary students in their internship placements. For the final science lesson assignment, the instructor required PSTs to include CT within the lesson they designed.

Participants

This study includes data from 39 PSTs with science teaching responsibilities who were enrolled in two sections of the elementary science methods course. PSTs were senior-level (final year) undergraduate Elementary Education majors. Within this cohort, they self-identified as follows: White females (n = 24); Asian or Asian-American females (n = 5); Black or African American females (n = 2); Hispanic or Latina females (n = 2); Multiracial females (White and Hispanic/Latina, n = 2); White males (n = 2); Multiracial males (White and Asian/Asian-American, n = 1; White and Hispanic/Latino, n = 1).

Seventy-five percent of these PSTs (29 participants) had never heard or learned about CT prior to this course. Two thirds of them stated that they either agreed or strongly agreed with the statement, "I am experienced in using educational technology," and nearly all of them (85%, 33 participants) felt confident in using the computer for instruction.

Curricular Module on Computational Thinking

The curricular module on CT consisted of three consecutive class sessions (2 hours and 45 minutes each). (Brief highlights of the project and modules can be found at www.terpconnect.umd.edu/~cabrera1/STEMC/ and https://stemforall2018.videohall.com/presentations/1174).

Session 1 – Intro to CT and the NGSS. During the first course session, PSTs were introduced to CT as a Core Science and Engineering Practice in the NGSS with the potential to help prepare all students – not only those with access to specialized technology or computer science courses - for STEM careers if they choose. They explored CT characteristics (CSTA & the ISTE, 2011) and their applications to the elementary classroom. Specifically, small groups used resources from the CSTA and the ISTE (2011) CT Resource Guide to create posters to illustrate a given CT skill and what they thought teaching the skill could look like in the classroom.

Skills included the following: (a) Representing data through abstractions such as models and simulations, (b) Automating solutions through algorithmic thinking, (c) Formulating problems in a way that enables the use of a computer and other tools to solve them, and (d) Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources.

Session 2 – CT Challenges through robotics. During the second course session, PSTs engaged in a hands-on CT experience solving programming challenges with LEGO Mindstorm, KIBO, and Code-a-Pillar robotics tools. They reflected on the CT characteristics they employed and anticipated the benefits and challenges of engaging elementary learners in CT.

Session 3 - CT integration in elementary science through citizen science. During the third course session, PSTs engaged in a community based science activity (Cornell Lab of Ornithology's Celebrate Urban Birds; see https://celebrateurbanbirds.org/). In the activity, they were introduced to a taxonomy of practices for the inclusion of CT in science education (Weintrop et al., 2016), consisting of four components: (a) data practices (b) modeling and simulation practices (c) computational problem solving practices (d) systems thinking practices. They identified the CT practices and science content they thought were embedded in the activity.

Data Sources

To gain insight into our research question, "Following participation in a curricular module on CT, what is the nature of PSTs' beliefs about CT integration in their elementary science classrooms?", we focused on three qualitative data sources.

Written reflections. Immediately following the implementation of the CT curricular module, participants completed individual written reflections, in which they described anticipated benefits and challenges of CT integration and gave examples of how CT practices could be integrated into science teaching practice in elementary classrooms. These reflections were a required assignment in the course and were graded by the course instructor.

In-class drawing activity. Before and immediately following the implementation of the CT curricular module, PSTs also completed a drawing activity in which they were asked to draw their students engaged in CT while learning science. They were asked to explain (a) what CT meant to them and (b) what they intended to communicate through their drawings. This in-class activity was not a graded assignment.

End-of-semester focus group interviews. On the last day of class, a randomly selected subset of PSTs (n = 12) participated in focus group interviews (four groups of three PSTs each), in which they discussed their views on (a) science-related understandings, skills, and practices CT could help learners develop; (b) benefits and challenges of CT integration; and (c) influence of the module on their views of CT. The interviews were approximately 20 minutes in duration and conducted by various members of the research team. Audio-recordings of the interviews were transcribed for analysis.

Data Analysis

We began our analysis of PSTs' beliefs about CT and CT integration into science instruction in their elementary classrooms with the recognition that more broadly we were seeking insight into their reactions to a major pedagogical innovation in science education.

Guided by the CAMCC (Gregoire, 2003), we examined the reform message presented in the elementary science methods course through the curricular module on CT.

We summarized this reform message as follows:

> Preparing students for future study and potential careers in STEM fields requires experiences with CT starting at a young age. At present, opportunities to develop CT are often not equally available for all learners. In response, new reforms in science education (NGSS) require the inclusion of CT in science for all learners, which has new implications for the teaching of science.

With this message as a reference point, we moved to the examination of our data sources in two phases.

First, we sought to describe change (or lack of change) in participants' beliefs about CT through their participation in the CT Curricular Module within the elementary science methods course. We applied a values coding approach, which Saldaña (2013) described as appropriate for investigation into beliefs. Saldaña said that *beliefs* are "part of a system that includes our values and attitudes, plus our personal knowledge, experiences, opinions, prejudices, morals, and other interpretive perceptions of the social world" (pp. 89-90).

In this phase, we were interested in participants' particular beliefs about what activities count as CT, and whether this view differed from their existing notions of what elementary science teaching entails. This point was important for us to understand because, as McNeill et al. (2016) described, teachers may talk about reform initiatives in different ways. Some may describe a reform (in this case, the integration of CT in science instruction) as truly requiring novel instructional approaches (responding to the reform with what Gregoire would call a "stress appraisal," 2003, pp. 165). Others may interpret the reform as encompassing general critical thinking or hands-on science and relabel their existing instruction (or ideas about instruction) using reform-based terms without changing their beliefs or actions (what Gregoire would call a "benign positive appraisal"; see Cohen, 1990, as cited in McNeill et al., 2016). In this phase of data analysis, we sought insight into whether the PSTs believed that CT represented something new in elementary science teaching – and if so, what did they believe was different about it?

After establishing participants' ideas about what counts as CT, we moved to our next phase of analysis, which entailed an examination of their beliefs about integrating CT into their own science teaching. We again applied values coding to gain insight into the extent to which they believed CT integration to be a valuable and feasible undertaking for their science teaching.

When examining their beliefs about the value of CT integration, we coded evidence of their beliefs about how CT supported (or failed to support) what they believed to be important in elementary science teaching – that is, what they saw as beneficial (or not) about making the effort to integrate CT into their science teaching practice. When examining their beliefs about the *feasibility* of CT integration, we coded evidence related to PSTs' own sense of self-efficacy for integrating CT into their science instruction (e.g., sufficient pedagogical content knowledge) as well as evidence related to participants' perceptions of their teaching contexts (e.g., availability of resources to support CT integration).

Results

Visions of CT in the Elementary Science Classroom

We first examined participants' drawings and written explanations in response to the prompt, "Draw your students engaged in CT while learning science." Our purpose was to gain insight into how participants understood CT in relation to their elementary science instruction. Specifically, we were interested to see whether participants demonstrated a view of CT as compatible with their existing elementary science instruction, and if so, the nature of the pedagogical shifts (if any) they envisioned themselves making to incorporate CT into their science teaching.

Three major categories of drawings emerged, which we interpreted to exist on a continuum (see Figure 1). At one end of the continuum, we interpreted a view of CT as completely separate from participants' existing elementary science instruction and curriculum (Category 1). At the other end of the continuum, we interpreted a view of CT as already completely embedded in participants' existing elementary science instruction and curriculum (Category 3). In the middle of the continuum, we interpreted a view of CT as compatible with participants' existing elementary science instruction and curriculum, but requiring some pedagogical shifts in order to integrate it (Category 2). This middle category best represents the view of CT that we hoped to convey through the CT curricular module within the elementary science methods course.

In addition, we included a fourth separate (i.e., not on the continuum) category for those drawings for which we were unable to interpret how (or whether) the participant related CT to science instruction (Category 4). Figure 2 shows the proportion of drawings we interpreted belonging to each category.

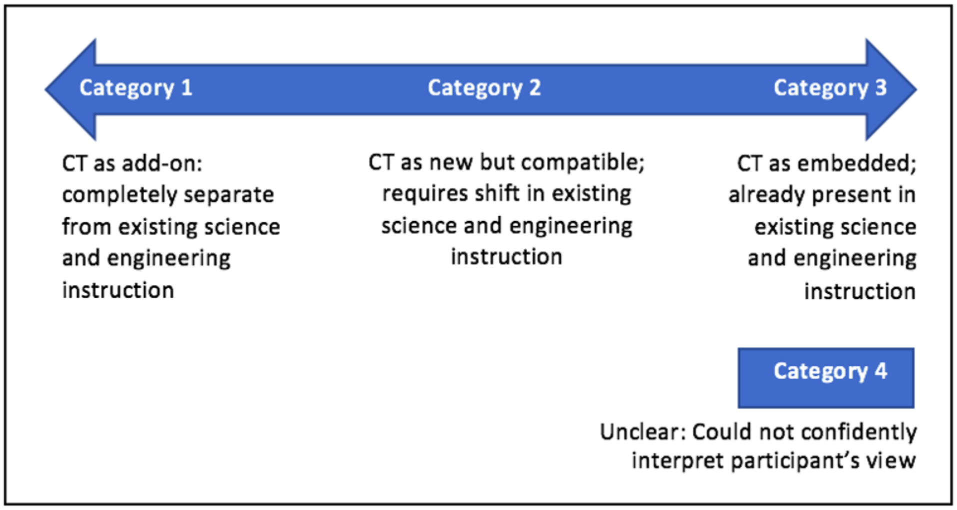

Figure 1. *Emergent categories describing our interpretations of participants' views of the relationship between computational thinking and elementary science and engineering.*

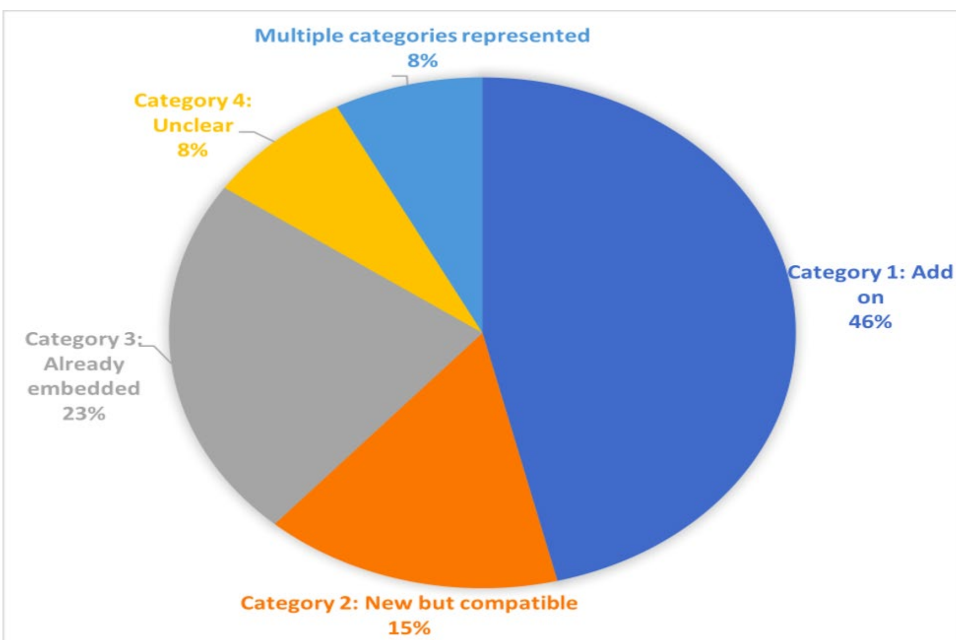

Figure 2. *Percentages of drawings coded within each category.*

Computational thinking as curriculum add-on. We grouped the largest percentage of drawings (45%, or 18 of 39) within Category 1 – CT as Add-On. Preservice teachers whose drawings were included within this group typically responded to the drawing prompt by drawing students engaged with the robotics tools that were introduced during the CT Module within the elementary science methods course. In these drawings, we did not interpret preservice teachers making connections between CT and the elementary science curriculum they were responsible for teaching.

Computational thinking as already embedded in the science curriculum. The next most common category was Category 3 – CT as Already Embedded (23%, or nine of 39 drawings). These participants drew students engaged in science and engineering activities that were a part of the elementary science and engineering curriculum, which they saw as encompassing CT elements such as working with data or troubleshooting. Troubleshooting was a skill preservice teachers used when programming robots during the curricular module on CT within the elementary science methods course.

In these drawings, we at times interpreted participants' viewing CT-integrated science as inquiry-based science or active learning. However, in these cases we did not interpret a view that the learning activities depicted in the drawings were being *adapted* in some way to include CT. Rather, we interpreted a view that CT was already built-in to the activity.

A small number of drawings (8% or three of 39) were grouped as Category 1 (CT as Add-On) *and* Category 3 (CT as Already Embedded) and coded as Multiple Categories Represented. In these cases, participants drew multiple images on the page: some that showed students engaged with the technology tools presented in the methods class (Category 1), and some that showed students engaged with their existing hands-on science and engineering curriculum activities, as historically taught (Category 3).

Computational thinking as science curriculum enhancement. We interpreted another group of drawings (15% or six of 39) to represent the view that CT was compatible with existing science and engineering activities within the curriculum but would require some pedagogical adjustments to incorporate (Category 2). In these examples, PSTs drew their students learning about existing curriculum topics through activities that required the use of particular CT practices introduced in the CT module within the elementary science methods course. We interpreted participants making adjustments to the existing curriculum in order to incorporate the CT practices, rather than holding the assumption that the CT practices were present in the existing curriculum.

No clear connection between computational thinking and instruction. Finally, for a small number of drawings (8% or three of 39), we were unable to interpret PSTs were envisioning CT in relation to science instruction (Category 4 – unclear). In these cases, preservice teachers represented CT practices introduced during the CT module within the elementary science methods course, but generally listed the practices rather than relating them to science teaching and learning.

Value and Feasibility of CT Integration

For the second part of our analysis, we examined participants' perceptions of the value and feasibility of CT integration in the elementary science classroom. We also examined the extent to which these perceptions varied with the different visions of CT integration in the elementary science classroom described above.

Value. As participants described what they saw as valuable about CT integration, we interpreted five key ideas. Most prominently, participants said that student engagement in CT would help them develop problem-solving skills that would be useful both in the classroom and the real world. For example, by engaging in CT practices, students would gain experience breaking down problems into smaller parts, recognizing patterns, and using and analyzing data to help solve problems.

Relatedly, participants saw value in CT's potential to cultivate key attitudes and dispositions in students that would benefit them in the classroom and in life. These dispositions included persistence, resilience, and the ability to collaborate with others.

Two other key ideas emerged about the value of CT integration as related to preparation for potential STEM careers. First, participants explained that CT integrated classroom activities could spark student interest in STEM, which could encourage continued involvement — including among students typically underrepresented in STEM careers. Additionally, participants suggested that CT integrated classroom activities could help students develop skills necessary for careers in STEM. Finally, a less frequent but reasonably prevalent idea was that CT integration in the science classroom could provide experience working with technology.

In examining how the three groups of participants perceived the benefits of CT integration, we noted some common themes across the groups as well as some variation. For all three groups, participants most strongly emphasized that CT integration could help students develop problem-solving skills, attitudes, and dispositions. Participants who appeared to understand CT integration as adding on technology-rich activities (such as robotics) to the science curriculum (Group 1) or as enhancing the science curriculum by adapting it to incorporate CT (Group 2) were more likely to cite gaining experience with technology as a potentially valuable aspect of CT integration when compared to their counterparts who saw CT as already embedded in the existing curriculum (Group 3). They were also more likely than Group 3 to perceive CT integration as valuable for helping students develop skills for STEM careers.

Feasibility. In examining the extent to which participants perceived CT integration as feasible, we again noted a number of overarching themes. The most prominent perceived threat to the feasibility of CT integration was a lack of resources, technology, or funds to support CT-integrated science teaching. Also prominent was a concern among participants that they had limited time for teaching science, let alone more complex science lessons that integrated CT. Generally speaking, they saw this constraint as a result of the emphasis on reading and math (tested subjects) at the elementary level. A third issue participants raised related to teacher learning, and the notion that CT integration takes time and effort for teachers to learn how to do effectively, and some teachers may be resistant to change. These concerns emerged within all of the groups of participants, regardless of how they envisioned CT in relation to the science curriculum.

In addition to these themes, we noted some additional concerns that were more prevalent in some groups than others (Table 2). Participants who saw CT integration as adding on to the curriculum (Group 1) were most likely to discuss the challenge of adapting the curriculum to incorporate CT, at times stating that teachers may lack the freedom to make curricular adaptations. These participants, along with participants who perceived CT integration as curriculum enhancement (Group 2), also cited equity concerns related to technology — particularly the concern that some students would have access to and experience with technology at home, and others may not. This concern did not arise amongst participants who saw CT as already embedded in the science curriculum (Group 3).

Similarly, participants from Groups 1 and 2 also saw CT as potentially challenging or frustrating for students, since it represented a new way of thinking and doing in the classroom. This concern also did not arise in Group 3, who perceived CT as already embedded in the science curriculum, and not representing a major shift for students.

Table 1
Cross-Group Comparisons of Perceived Value of Integrating CT Into Elementary Science Instruction

Perceived Value	Group 1: CT as Add-On	Group 2: CT as Curriculum Enhancement	Group 3: CT as Already Embedded
Students develop problem-solving skills	Common	Common	Common
Students cultivate important attitudes and dispositions	Common	Common	Common
Students become interested in STEM	Occasional	Occasional	Occasional
Students develop skills for STEM careers	Occasional	Occasional	Rare
Students gain experience working with technology	Occasional	Occasional	Rare

Focal Cases

The following three cases provide illustrative examples of how participants perceived CT integration in different ways, and how different ways of perceiving CT integration may have shaped participants' views of its value and feasibility in the elementary science classroom.

Table 2
Cross-Group Comparisons of Perceived Threats to CT Integration in Elementary Science Instruction

Perceived Feasibility Threat	Group 1: CT as Add-On	Group 2: CT as Curriculum Enhancement	Group 3: CT as Already Embedded
Lack of resources, technology, or funds	Common	Common	Common
Limited time for teaching science	Occasional	Common	Occasional
Teacher learning curve	Occasional	Occasional	Occasional
Difficulty of adapting existing curriculum	Occasional	Absent	Absent
Equity concerns related to technology access	Occasional	Occasional	Absent
Student frustration	Occasional	Occasional	Absent

Sarah: "Bringing the world of computers and digital tools into our very own classrooms." Sarah was a PST interning in a second-grade classroom. In responding to the prompt, "Draw your students engaged in CT while learning science," she drew her students learning to code while engaging with the Fisher-Price Code-a-Pillar toy and educational robots — two innovations modeled in the methods course (Figure 3).

Sarah stated that the most impactful part of the CT Module was the day the PSTs learned about CT through robotics. She explained that the learning activities gave her "a glimpse into how it is possible to bring the world of computers and digital tools into our very own classrooms" (Sarah, blog post). We coded her drawing within Category 1: CT as Add-On, since we interpreted the learning activities she depicted as separate from her regular second-grade science curriculum.

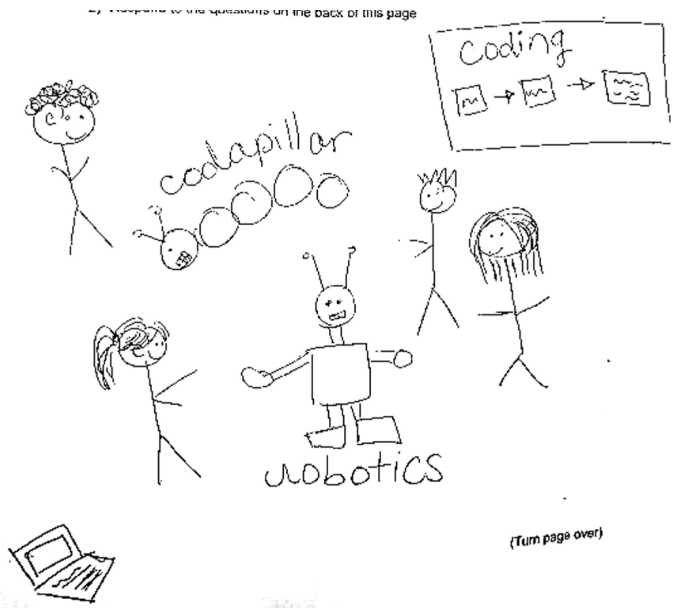

Figure 3. *Sarah's response to the prompt: "Draw your students engaged in CT while learning science." Sarah's commentary: "My students are learning how to code, using the Code-a-pillar and small robots. They are also using Chromebooks to code and record their results."*

Like her peers, Sarah saw value in CT integration in terms of its potential to help students develop problem solving skills and dispositions. For example, she said that engaging in CT could help students learn to work collaboratively with others — a skill that would benefit them throughout their lives. She also believed, like a number of her Group 1 counterparts, that the problem-solving opportunities afforded by CT-integrated learning activities had the potential to spark student interest in STEM and STEM careers. She explained,

> In some cases our students come into our classrooms having a false understanding that learning about science and math is tedious, too difficult, boring, unnecessary, etc. However, by basing our lessons around the computational thinking process of problem-solving, students can become re-invigorated for learning science and mathematics. This will hopefully encourage them and challenge them to pursue STEM fields later down the road. (Sarah, blog post)

Regarding perceived challenges of CT integration in science, Sarah appeared most concerned about the lack of science instructional time and the lack of funding to purchase technology tools for the classroom. She also raised the concern that CT was challenging to integrate into the existing elementary science curriculum. In providing feedback on the CT Module within the elementary science methods course, she stated,

> I think it would be beneficial for us to see how we can actually include [CT] in lesson plans that are given to us by the curriculum. Because that was my issue. My teacher gave me a curriculum, or a lesson plan straight from [county] curriculum that was like: "Do this." But then I didn't know where to add the computational thinking. (Focus group interview)

This concern emerged from other counterparts in Group 1, but not from her peers from Groups 2 or 3, who saw CT as enhancing or as already embedded in the science curriculum.

Evan: "Too often the science lesson is just reading from the textbook and filling out a worksheet." Evan was a resident interning in fourth-grade classroom. In depicting his students engaged in CT while learning science, Evan drew students creating toothpick and marshmallow structures as part of an engineering lesson and using troubleshooting to improve their designs (Figure 4).

Evan said that CT "is the way that all science should be taught" and that "too often the science lesson is just reading from the textbook and filling out a worksheet" (Drawing commentary). Our team interpreted his drawing as representing Category 3: CT as Already Embedded in the Curriculum, since he showed his students engaged in steps of the engineering design process articulated in the NGSS (i.e., optimizing design solutions).

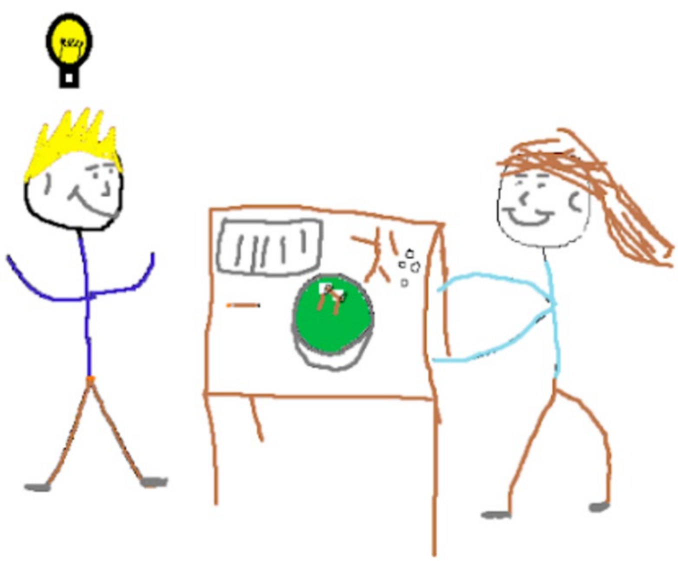

Figure 4. *Evan's response to the prompt: "Draw your students engaged in CT while learning science." Evan's comments: "The main aspect I wanted students to focus on was their ability to approach a problem and problem solve. This is a highly detailed picture of two of my students figuring out ways they can make their structure more stable. On the desk, they are using data from a previous attempt to see if they can build upon it."*

Evan described CT as an essential skill for students, particularly because it could help them develop problem solving skills and dispositions potentially useful throughout their lives. He also said that early engagement with CT had the potential to increase student interest in STEM.

Like other peers whose drawings we interpreted as Category 3, Evan did not emphasize gaining experience with new technologies as a principle dimension of

CT integration for students. For example, unlike Sarah, who highlighted the use of new classroom technologies (Fisher Price code-a-pillars) in her drawing, Evan used an example of where he already saw computational problem-solving practices (e.g., troubleshooting) embedded in the hands-on ("unplugged") learning his students were already doing in the classroom. In general, we interpreted Evan's view of CT integrated teaching as incorporating the use of active or hands-on learning approaches to teaching existing curricular content, such as the engineering design process.

Evan's concerns about the feasibility of CT integration related to his commitment to active learning in the science classroom. Namely, he saw CT integrated teaching as requiring more time and effort on the part of the teacher. He stated, "While the activities using CT would be fun, they require a lot of time and that is a precious resource in the teaching world" (Blog post).

Unlike some of his peers in Groups 1 and 2, Evan did not focus on technology — including equity issues related to technology access — as potentially affecting the feasibility of CT integration. While he did see CT as involving students in problem-solving, unlike peers in these other groups, he did not state that CT had the potential to frustrate students. Rather, he focused on the positive affective potential of the hands-on learning experiences afforded by CT integrated science teaching.

Taylor: "If we teach our kids these skills, we can shape a better world for the future." Taylor was a resident interning in a first-grade classroom. Taylor's drawing of her students engaged in CT while learning science depicts children outside conducting field research on river organisms (Figure 5). She explained that students would collect and analyze data to understand the river system. They would examine trends in their data to make predictions about how animal populations could be affected by human activity. Our team interpreted her drawing as Category 2: CT as Curriculum Enhancement, since she seemed to connect CT practices (data practices and systems thinking) with her first-grade life science content.

In her blog post, Taylor stated that the most valuable aspect of CT integration in the elementary classroom was its potential to help students approach, analyze, and resolve real world issues:

> [CT skills] will not only help them in their personal lives… but also will equip them to tackle problems that we all have such as bettering the environment. … This is the most important reason to teach people CT when they are young, because we need people who are equipped with these skills to help lead the way to finding solutions to the problems we face as a species. It we teach our students these skills, we can shape a better world for the future.

Taylor said that engaging students in CT at a young age could better prepare them for possible future STEM jobs. She also said that developing CT skills had the potential to help students in their everyday lives, by giving them the ability to "approach problems practically, make predictions, and try different methods of solving problems" (Blog post). She said this ability had potential value for helping people develop leadership, improve job performance, and enhance their relationships.

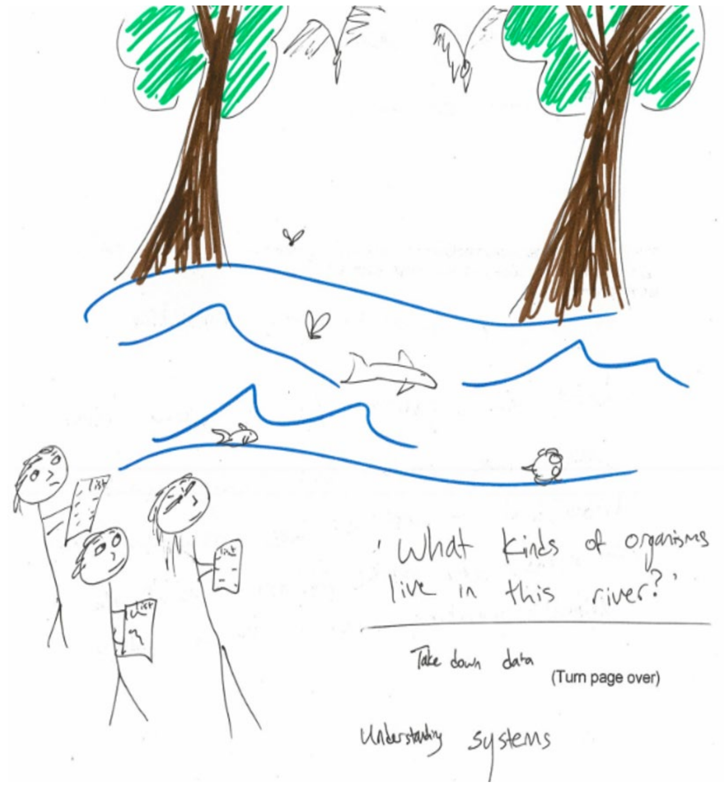

Figure 5. *Taylor's response to the prompt: "Draw your students engaged in CT while learning science." Taylor's comments: "My students were collecting data on organisms in a nearby river which we could then analyze to understand a system. We could later look at trends and make predictions about the animal populations based on human activity."*

Like her peers in Group 2 who saw CT as enhancing the science curriculum, a major concern Taylor expressed about the feasibility of CT integration related to "finding enough time to squeeze it in the curriculum." She explained that many schools typically placed most of their focus on reading and math due to standardized testing. Related to the deemphasis of science in elementary schools, Taylor was also concerned that students' natural interest in science could already have been depleted by later in elementary school and that reigniting their interest in science (and CT) could require extra effort on the part of the teacher — particularly in the upper grades.

Discussion

This study explored PSTs' beliefs about the reform effort of CT integration science education after participating in a CT module in their elementary science methods course. Using Gregoire (2003)'s CAMCC as an analytical lens, we sought to understand how and why PSTs responded to the reform message as threatening or supporting their current teaching practices.

We conceived that those who saw CT integration as an "add-on" (Group 1) or a "curricular enhancement" (Group 2) aligned with Gregoire's conception of participants who view the reform message as *threatening* to their current teaching practices. Therefore, these teachers would be likely to alter the "status quo" of instruction in order to integrate CT. Those who saw CT as already embedded in the ways they teach science (Group 3) aligned with Gregoire's conception of teachers who view the reform message as *supporting* their current practices. These participants may be unlikely to alter instruction in ways that authentically integrate CT.

These encouraging findings suggest that PSTs may react in support of the NGSS CT policy-driven pedagogical innovation. This finding is major, since so many prior policy-driven innovations in education (c.f., Math Wars and Whole Language vs Phonics Approaches) have faced educators' resistance. Next, we discuss strategies for future iterations of our study, and more generally, for the integration of CT into science methods courses, to encourage teachers to understand how CT could enhance the existing curriculum.

Operationally Defining CT

Despite having a common CT-learning experience, participants had varying interpretations of CT. Even though all PSTs had been exposed to similar CT definitions and CT-learning activities, they were dissimilar in how they applied these definitions to classroom teaching. Designing effective practices for integrating CT into K-12 education is currently a significant problem for the field, because the field has not agreed on how to define and thus operationalize CT. There is a need to develop resources in order for teachers and teacher educators to share a common understanding of CT in practice. In subsequent iterations of the module, we saw areas where we could adjust how we framed CT in order to address areas of confusion and better emphasize possible ways CT could enhance what was already happening in the elementary science classroom.

Developing CT-Aligned Pedagogies

Many teachers believed CT was an add on (Category 1, as exemplified by Sarah). Sarah indicated that using the code-a-pillar toy in instruction was akin to CT instruction but did not elaborate on how the students were using CT with the tool. This response was a common one from PSTs who viewed CT as an add on. As previous research on teaching learning about CT has suggested (Bower & Falkner, 2015; Yadav et al, 2014), teachers were inclined to believe that integrating tools or technology was the essence of CT integration.

The issue of conflating CT with technology is compounded when considered alongside teachers' perceived challenges about CT integration. All three categories of teachers indicated that lack of resources, technology, and time to teach science restricted their ability to teach CT. These findings suggest that a need to develop CT-aligned pedagogies embedded in common classroom resources (so as to not require expensive technology tools) and existing curriculum (so as not to take more time).

In subsequent iterations of the module, we addressed this challenge by presenting varying "plugged" and "unplugged" activities to diversify how programming and algorithmic thinking (e.g., creating science content-based animations in Scratch Jr; completing an unplugged CT measuring challenge). We also infused the robotics session with science content (different science missions they could choose from).

Clarifying How CT Is Related to Inquiry-Based Practices

Teachers commonly conflated CT with inquiry-based practices or active learning (Category 3, as exemplified by Evan). These participants focused on the disposition building components of CT, such as problem solving and troubleshooting, but did not necessarily connect these to computational practices. Our previous research has indicated that in-service teachers also conflate CT practices with scientific inquiry (Ketelhut et al., 2019).

This finding further highlights a need to clarify how CT practices are but related to inquiry-based practices. Because all three teachers believed that attitude and disposition development were important aspects of CT learning, it is essential to maintain these components of active learning instruction in the development of CT pedagogies.

Summary Implications for CT Teacher Education

In summary, the findings from this study indicate several insights for science teacher educators. We present a couple of recommendations. First, the diversity of definitions of CT appears to result in uneven beliefs on integration of CT. We strongly recommend choosing a single definition of CT to operationalize its integration with science, as we have done in our next iteration. Second, given the potential conflation of technology tools with CT thinking, we recommend using a variety of plugged and unplugged activities for teaching CT.

While our study was directly about preservice teacher beliefs, the results have implications for teacher educators too. During the time of the *National Science Education Standards* (National Research Council, 1996) a major goal of elementary science pedagogy was to prepare the PSTs to teach inquiry-based science. Almost all instructors were knowledgeable about inquiry-based science due to personal experience with science or having degrees in science. However, the NGSS requires the science pedagogy instructor additionally to be prepared to teach about CT and how it may be fruitfully integrated into science education, which is different from the background of many science teacher educators. Therefore, we also suggest that additional professional development is needed for science teacher educators to become comfortable with this new role of facilitating CT in science education.

Limitations

We acknowledge several potential limitations of our study. First, data for this study were collected midsemester immediately after the CT module. PSTs developed CT-infused lesson plans at the end of the semester, which were not analyzed as part of this study. Being challenged to include both CT and science content into a lesson plan they will be teaching in their classroom has potential to move PSTs toward the center of the continuum (i.e., including both CT and science content), which is something that we incorporated into subsequent CT modules.

Regarding data collection, the drawing prompt may have been leading. The prompt in this study asked participants, “Draw your students engaged in CT while learning science." In subsequent iterations, we changed the prompt to, "Draw yourself teaching science the best way you know how," and then analyzed whether "the best way" they knew how included CT.

Additionally, blog posts were graded class assignments. Therefore, the responses may have been biased to include what the participants thought the instructors wanted to read, even though the instructor tried to minimize this limitation by explaining that blogs were to be honest and reflective, not positive. Further, grading was based on completion, not on the content of the blog. Still, the blog responses could give some insight into how participants understood and thought about CT. We did, however, decide to make some changes to the prompts.

In this study, we noted that PSTs' perceptions of their teaching contexts related strongly to their perceptions of the feasibility of CT. However, we did not specifically collect data on how they viewed their teaching contexts in terms of support for CT integration. We decided to collect this data (via a survey) in subsequent iterations.

Finally, the duration of the module for this science methods course was limited to 8.25 cumulative hours of in-class instruction. We provided additional CT learning opportunities for participants in a science teaching inquiry group composed of PSTs and their mentors. However, the findings from this additional CT learning experience are not reported in this study.

Conclusions

This study provides insight into PSTs' beliefs about CT integration as a reform effort in science education following an introduction to CT in their elementary science methods course. PSTs generally expressed receptivity to the notion of CT integration, and saw CT as beneficial for elementary students. Introducing CT and CT integration through the use of robotics and citizen science appeared to contribute to PSTs' positive reactions to CT. However, at times we noticed possible confusion among PSTs about the nature of CT (such as the view that it requires technology), or about the relationship between CT and scientific inquiry (such as the view that CT is a collection of discrete skills (e.g., graphing) that can be used while doing science, rather than a different way of thinking while doing science). This finding suggests that future iterations of the module — and teacher education efforts around CT in general — should support PSTs in developing an understanding of the how scientific inquiry, educational technology, and CT connect and differ.

Additionally, because the module suggested that PSTs implement a reform that is not yet widespread in elementary science education, PSTs identified potential challenges they may face in implementing the reform. A major implication of this work is that PSTs could benefit from discussions about how to integrate CT in an unplugged manner or without the use of specialized educational technologies (beyond those readily accessible in their schools), and examples of science lesson plans that integrate CT in developmentally appropriate ways, particularly in the early elementary grades.

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