ABSTRACT

Title of Dissertation: EXPLORING THE IMPACT OF A COMPUTATIONAL THINKING MODULE FOR MATHEMATICS AND SCIENCE METHODS COURSES

Peter Moon, Doctor of Philosophy, 2024

Dissertation directed by: Associate Professor Janet Walkoe, Department of Teaching and Learning, Policy and Leadership.

Computational thinking (CT) has great potential for enhancing mathematics and science lessons in K-12 education. Numerous studies demonstrate that under the right circumstances, CT integration in math and science can improve student learning and promote deeper understanding. However, teacher education currently does not include preparation for using CT in the classroom on a widespread scale. Instead, most current CT courses or professional development (PD) opportunities for teachers are taught by a local CT researcher who can only reach a limited number of teachers.

This qualitative three-article dissertation summarizes the development, implementation, and effects of a five-lesson module on CT designed to be integrated within a math & science

methods course or a similar course for teachers. The goal of this module is to provide learning about CT within most teacher education programs without substantially affecting that program's requirements for teachers (i.e., adding a new course).

In Study 1, "Module Implementation in a Mathematics and Science Methods Course," I describe the module activities, the CT knowledge of the teacher candidates who participated in the study, and how that knowledge evolved. I argue that participants' understanding of CT expanded from a limited scope to a wide variety of practices and skills, and that the experience-first design helped them build knowledge of CT as distinct from knowledge of their discipline.

In Study 2, "Use of CT Knowledge as Classroom Teachers," I discuss sets of interviews with two teachers who had previously participated in the CT module in different years, analyzing commonalities and differences in their organization and use of CT knowledge. I argue that the Preparation for Future Learning (PFL) (Bransford & Schwartz, 1999) perspective is particularly important when considering the impact of the CT module.

In Study 3, "A Faculty Workshop on CT Implementation with Mathematics and Science Methods Courses," I discuss the effects of a summer workshop with methods instructors from universities throughout Maryland, noting different perspectives around what "counts" as a CT activity, and two implementation profiles for CT that instructors used that fall. I argue that the PFL perspective is important to consider for methods instructors' CT integration.

EXPLORING THE IMPACT OF A COMPUTATIONAL THINKING MODULE FOR MATHEMATICS AND SCIENCE METHODS COURSES

by

Peter Francis Moon

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Advisory Committee:
Associate Professor Janet Walkoe, Chair
Associate Professor David Weintrop
Professor Andrew Elby
Associate Professor Tamara Clegg, Dean's Representative
Postdoctoral Fellow Margaret Walton

Dedication

To my two favorite ladies,

Nickole and Brandy,

for modeling what it means

to thrive even when we need to survive.

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Chapter 1: Introduction

Personal Relevance

Before I came to this work, I was a math teacher at a private Catholic school in Baltimore, MD. In my second year, one of our science teachers left and, thanks to some familiarity with C++ from writing little text adventure games in college, I happened to be the first choice to take over his class, an introductory programming elective. I was not really prepared for this – my formal training in programming consists of a three-week summer course in C++ that I did when I was 12 – but there was no real other option.

As it turned out, my inexperience turned out to be somewhat of an asset. I was fortunate to have inherited a terrific curriculum and built on it by adding a project that spanned multiple units, “Mr. Calculator,” where students had to consider how to program different math functions into a program in C++. At first, we stuck to basic arithmetic, exponents, and other similar operations. These activities were surprisingly popular, especially the exponent function, as many students said the process of creating an exponent algorithm helped them better understand how exponents worked mathematically. As we continued into the second semester, students had the freedom to choose and develop a larger program as a final project. Many revived their old Mr. Calculator code into upgraded versions, including functions like graphing lines, solving equations, and even some basic regression. One particularly enterprising student gave his Mr. Calculator a “Mr. Statistics” subroutine that could even do some quadratic regression.

What caught me by surprise in this experience was how much math many of my students were learning. I taught many of the same students in math classes, as well as other students, and noticed anecdotally that many of the programming students had a better and deeper grasp on what some of the math they were being asked to do meant and how it worked. They were also often engaging with math that was beyond what they were learning in class: the Mr. Statistics developer, for example, had not taken any kind of statistics course until the year *after* he designed a quadratic regression function. I generally thought that a direct engagement with the process through the context of writing a function was leading to this deeper understanding.

I should also make it clear that many activities in this class did not yield this same positive experience. In fact, my midterm (“Please make a program that will play the game *Battleship* against me”) was, in the words of a student turning in his project, “Uh, *not great,* Mr. Moon.” Many times, students did not see the mathematical connections with the work we were doing. I had no idea why some activities worked well and others did not.

At the time, I had not heard of “computational thinking.” I had just started my M.A. in Teaching, having started at the school with a B.A. in Psychology. However, my experience generally aligned with what I later learned about CT’s potential support for learning when integrated into math and science lessons. As I will discuss below, it is certainly a promising partnership, but requires careful consideration to be "mutually supportive" (Fofang et al., 2020).

I approach this work as a "believer" in the sense that I have seen the value of CT activities in helping students learn about math. But I am also aware of the delicate nature of this support and believe that teachers need a solid understanding of how CT can be supportive to best enhance learning for their students. With this work, I support that understanding by looking at the knowledge teachers and teacher educators hold about CT and how that develops through learning experiences.

Overview

In her influential paper, (Wing, 2006) described CT as "a fundamental skill for everyone," (p. 33), citing applications to statistics, biology, and a myriad of other disciplines and recommending that we teach CT to all children. Further work has argued that CT can be supportive of learning across the K-12 level, particularly in STEM disciplines (e.g., Weintrop et al., 2016). However, while efforts to expose teachers to what CT is and how to use it in the classroom exist (e.g., Yadav et al., 2014), there remain significant open questions about how best to prepare future teachers to utilize CT in their classrooms. As CT is a burgeoning field, there are also few efforts to study the effects of CT instruction in teacher education and teacher knowledge of CT, and those that exist tend to be localized to the effective range of a handful of researchers distributed sparsely across a few universities.

This work is the summary of an effort to create, deploy, and evaluate a module of five lessons on CT, set within a mathematics & science methods course for middle school teacher candidates. We examine the effects on teacher candidates that took the course at multiple timepoints: before, during, after, and an extended period of time after the module. In addition, we present the ripple effects of a workshop presenting this design to professors at universities across the state who later integrated CT within their own courses, both on those professors and the students they taught.

Overview of the Studies

Study 1, "Module Implementation in a Mathematics and Science Methods Course," is published with co-authors Joshua Himmelsbach, David Weintrop, and Janet Walkoe in the *Journal of Pedagogical Research,* under the title "Developing preservice teachers' intuitions about computational thinking in a mathematics and science methods course." We describe the lessons of our module and the activities within them, as well as the analysis of video recordings from throughout the module to identify the CT knowledge of the teacher candidates who participated in the study, and how that knowledge evolved as they progressed through the module. We argue, evidenced by quotes from class discussions, class artifacts created throughout the module, and the integrated lesson plan assignment that participants' understanding of CT expanded from a limited scope to a wide variety of practices and skills, and that the experience-first design helped them build knowledge of CT as distinct from knowledge of their discipline.

In Study 2, “Use of CT Knowledge as Classroom Teachers,” I discuss sets of interviews with two teachers who had previously participated in the CT module in different years, analyzing commonalities and differences in their organization and use of CT knowledge. I argue that these teachers often conceptualize CT differently and use it in different ways than what we intended to include in the module, although both expected and unexpected knowledge teachers associated with CT tended to lead to productive classroom practices. I also note that the Preparation for Future Learning (PFL) (Bransford & Schwartz, 1999) perspective is particularly important when considering the impact of the CT module, as we do not expect teachers to be done learning about CT after this five-week module.

In Study 3, “A Faculty Workshop on CT Implementation with Mathematics and Science Methods Courses,” I discuss the effects of a summer workshop with methods instructors from universities throughout Maryland. I analyze different conceptualizations of CT among instructors that participated, in particular different perspectives around what “counts” as a CT activity. I also discuss two implementation profiles for CT that instructors used that fall, by two instructors from somewhat different backgrounds who nonetheless planned to implement CT in their methods courses in quite similar ways. I argue that the PFL perspective is important to consider for methods instructors’ CT integration, and that instructors being on a productive track may be more important than having a complete plan for integrating CT within their course.

In these studies, we seek to answer the following research questions:

Research Questions

Study 1 - Module Implementation

1. *How does an experience-first module on computational thinking shape teacher candidates' emerging computational thinking understandings?*
2. *After exploring this module, how do teacher candidates operationalize their own conceptualizations relative to existing computational thinking frameworks?*

Study 2 - Long-Term Effects on Knowledge in Practice

3. *How do teachers use knowledge about computational thinking in practice when planning an integrated lesson for their classroom?*

Study 3 - Impact on Other Instructors' Courses

4. *How do instructors conceptualize computational thinking in the context of a summer workshop?*
5. *How do instructors approach integrating computational thinking into teaching methods coursework after a summer workshop?*

Background

Computational Thinking in Mathematics & Science Education

CT-integrated mathematics shows promise as an instructional model. The potential of grounding mathematics instruction in concepts and practices from computing has a long history dating back to early work on the Logo programming language helping students better understand Geometry (Papert, 1972; Papert, 1980). Since this early foundational work, many projects have investigated ways programming, computers, and now CT, can serve as a productive context for supporting mathematical learning. Some projects continued to use the Turtle Geometry programming style started by Logo (Abelson & Disessa, 1986; Wilensky, 1995), while others explored other applications, like SimCalc, which supports algebraic functions, calculus, and Cartesian coordinate graphing (Kaput et al., 2002; Noss & Hoyles, 1996; Roschelle et al., 2000). A recent example is the Sphero.Math project (Weintrop et al., 2022), which has students design and implement programs as part of CT-integrated math lessons in fourth-grade classrooms. This work indicates that well-designed activities can link mathematics and CT in a "mutually-supportive" fashion (Fofang et al., 2020, p. 1391).

However, research has revealed how attempts to integrate CT into disciplinary contexts can fail to achieve the desired "mutually supportiveness." For example, in the Sphero.Math project one of the activities asked students to program their Sphero to follow a "prime number path" through a grid composed of prime and composite numbers. When the lesson was implemented, students did the math (found the prime numbers) first, followed by writing the code for the path which was perceived as a distinct activity from the mathematics by the learners (Fofang et al., 2020). This work demonstrates less productive approaches for CT integration: specifically, designing activities that tangentially involve math without integrating the CT task into the mathematical goals of the lesson.

A more productive example of CT in math integration can be seen with Bootstrap: Algebra, “an early-programming curriculum that is designed to teach key algebra topics as students build their own video games,” (Schanzer et al., 2015, p. 1). Throughout this curriculum, programming concepts are aligned with math concepts in the broader context of creating a video game. For example, in one lesson, the desired game feature is to “determine when game elements are off-screen,” (Schanzer et al., 2015, p. 2). To accomplish this, students must use Boolean logic and, to complete the conditional statements, must define proper algebraic inequalities to make the game behave correctly. By integrating the programming goal of the video game feature, students gain a practical motivation to master a concept in algebra. The programming task, then, encourages students to master this algebraic concept not in the abstract but for a desired goal.

All of this suggests that CT integration is a delicate art. It can support STEM instruction, but only under certain, carefully-constructed circumstances. We posit that teachers will then also need training on CT to make sure these integrations are successful.

The Importance of Teacher Education on CT

To integrate CT within K-12 STEM education, it is vital to make sure teachers are ready to use CT-integrated activities in their classrooms. Preparing them adequately entails that they are not only ready to deliver this, but also to do this in a way that is productive for students. Previous research with teachers has shown that they often conflate definitions in CT with other, inaccurate definitions; they believe it is difficult to teach and learn, and may not be easily integrated into the classroom (Cabrera, 2019); there is confusion over technical "jargon" in CT, and online or dictionary resources often present conflicting, insufficient, or non-specific definitions (Munasinghe et al., 2021). As the ones responsible for delivering this content to students, this level of readiness may be insufficient. Teachers need a strong understanding of CT, how to apply it in their domain, and recognize the value of CT in the STEM classroom.

Previous iterations of this module ran into a similar problem as found in this previous research: teacher candidates often conflated CT concepts with pre-existing knowledge from their domain. For example, one candidate noted that "anytime we're doing the scientific method, we're doing CT," describing CT as just another way of thinking about this approach. Another candidate, looking at "Modeling and Simulation Practices" under the CT Math & Science Taxonomy, used this to describe students working on building models of water molecules in class. Math teacher candidates were equally likely to conflate CT with existing concepts, noting that pattern-finding is already a mathematical practice and that students use algorithms all the time in math.

While the vocabulary used to talk about it often overlaps with terms from math and/or science, CT is a domain of knowledge distinct from both math and science. The term "algorithms" in CT, for example, describes not the practice of using algorithms (like a student might do in a math class routinely) but rather considering how to organize an algorithm to make use of a computational tool more efficient or accurate. To do this requires not only an understanding of what the algorithm is supposed to do, but how to effectively convey that in the language or resources of your computing tool. This takes a meta-cognitive step beyond what would typically happen in a math class, and distinguishes this and other skills & practices in CT from their similarly-termed counterparts in math and science. Teachers need to be aware of this distinction to take full advantage of how CT can enhance these classes. Conflating CT with practices in the math and science domains was a persistent problem in this module. Even when prompted to find differences between CT and their domain of practice, candidates often reverted back to finding similarities. For this reason, we decided to ground their understanding in two CT experiences before discussing academic frameworks and vocabulary. The goal of this novel Experience First, Formalize Later (EFFL) approach (Stats Medic, 2018), which we describe in greater detail in the next section, is to give candidates fresh experiences to draw on as they conceptualize what CT is. This mitigates the conflation problem by avoiding reliance on comparisons to the math and science domains, and instead drawing on these new experiences to build knowledge.

Teacher Education for CT in Mathematics & Science

Current Programs

A growing body of research has investigated effective approaches for introducing teachers (both pre-service and in-service) to CT through the design of effective coursework and professional development (PD) workshops. Several studies used the model of ongoing PD experience with sessions spanning the course of a year (Ketelhut et al., 2020; Yadav et al., 2018), leaning into the idea that effective PD should be an ongoing experience, not a single isolated session (Darling-Hammond et al., 2017). Other studies have emphasized the importance of including CT within the teacher preparation curriculum (Yadav et al., 2014; Mouza et al., 2017) so that teachers do not need additional workshops or supplementary coursework to develop a working knowledge of CT. Our work builds on these previous efforts by situating our CT module within a pre-existing mathematics & science methods course, as well as delivering it over a five-week period rather than a single workshop.

These programs are, at least in practice, highly localized. CT integration into teacher education is mostly possible at present due to a nearby researcher interested in creating materials for a guest lecture, workshop, or other PD on the subject. As such, the program can benefit teacher candidates at that particular university, and subsequently their students, but cannot have broader impact. To sustain impact and make it more equitable to all students, a few priorities should be considered. First and foremost, researchers should consider ways to make their materials and resources for teaching teacher candidates about CT available publicly. This will make it possible for instructors in other courses and at other universities to adopt the materials for their own students. Second, researchers should look for ways to ease adoption of their materials; for example, a series of lectures that fit within an existing course, as seen in (Yadav et al., 2014), may be easier to adopt than an entirely new course on CT.

Finally, designers should consider curricula for these integrations that rely on free, open-source resources as much as possible to further make them easier to adopt for universities, instructors, and students alike. The goal of these recommendations is that more teacher candidates would be exposed to instruction on CT within their teacher education coursework, and thus be better prepared to include it in their K-12 classes, use existing K-12 CT STEM integration activities in the classroom, and discuss the topic and its connections to STEM productively with students.

The final and most important way our current work differs from previous efforts in CT instruction in teacher preparation is that we use an experience-first (Stats Medic, 2018) design grounded heavily in teacher candidates' experiences with CT tasks. Most current CT instruction views current academic understanding of CT domain as information to be conveyed to teacher candidates. For example, the two-class program run by Yadav & colleagues (2014) teaches about five CT concepts ("Problem identification and decomposition, abstraction, logical thinking, algorithms, and debugging," (p. 5)) and then illustrates these concepts on the first day. We roughly reverse this order: teacher candidates participate in two CT activities in our first lesson, then brainstorm their own terms and definitions for "What is CT?" in the second lesson. It is not until the third lesson that teacher candidates are introduced to current frameworks to organize academic understanding of CT. This ordering allows for candidates to construct their own understanding of CT and take ownership of their own definition. Providing experience with CT activities before introducing vocabulary also reduces the possibility that vocabulary used to define CT will simply become entangled with existing ideas in math and science, because under this format, teachers have an experience with which to ground these terms and ideas other than their classroom content domain. Ideally, this empowers future teachers to have a more active role in understanding and using CT in the classroom.

Success Metrics for Current Programs

Programs to integrate CT within teacher education have evaluated teacher candidate knowledge growth in different ways. The most common method is a blend of open-ended and Likert-scale items exemplified in Yadav et al. (2014), which uses 21 Likert-scale questions to assess attitudes towards CT and its use in the K-12 classroom, as well as 3 open-ended questions for assessment of candidate understanding of CT. These items were also used by Mouza & colleagues (2017), and in both cases indicated growth in several, but not all, areas measured: the first study saw significant differences in the Definition of CT question and Classroom Integration Likert items, while the second saw growth in Definition of CT and Knowledge and Beliefs (and additionally noted that open-ended responses describing CT grew more specific and accurate).

Other research used different metrics. Rich & Yadav (2019) focused on teachers' implementation patterns for CT instruction, an approach shared by Rich, Yadav, & Larimore (2020). Other research examined whether teachers could recognize ways CT applied to science (Yadav et al., 2018), as well as teachers' views on CT, whether they were able to integrate CT into their classrooms, and how valid that CT integration really was based on reflections in after-school workshop sessions (Ketelhut et al., 2020).

The core evaluation posed in Yadav & colleagues' work (2014) offers a tried-and-tested method that demonstrably detects changes in teachers' views towards and understanding of CT. However, this method has two main gaps that we seek to fill. First, by using this pre- and post-survey design, we have no insight into the process of learning: we cannot see exactly what knowledge about CT the teacher candidates hold during the learning experience. Second, much like the final exam at the end of a class, this design offers no insight into teacher candidates' continuing knowledge about CT after they have left this course. We address these gaps, as described in the methods section below, by focusing our analysis on two sources of video data: one round collected during the class itself and a round of video-recorded interviews conducted at least a semester after the course module.

Methods Rationale

The methods described here consist of qualitative analysis focusing on interview recordings and transcripts, in-class recordings and transcripts, artifacts from coursework, and open-ended responses in surveys.

The qualitative analyses used throughout these studies aim to capture meaning from rich sources of data. For example, Paper 1 uses a combination of inductive and deductive codes to describe how teacher candidates discuss CT in the moment of learning and understand what this means about intuition and experienced-based knowledge about CT. Paper 2 uses a similar approach to capture how teachers think about and use CT for lesson planning long afterwards. These analyses, particularly the open-ended nature of the inductive codes, are well-suited to capturing conceptualizations about CT because we can capture a full range of ideas, even those not expected in our a priori assumptions. Our goal is to understand how teachers are thinking about CT in their own understanding, not just how that understanding fits with current research and frameworks on CT, so it is important to capture novel ideas as well as pre-existing ones.

Project Context and Participants

This project consists both of an effort to develop a CT instructional module for a particular math & science methods course and study its effects, as well as studying the effects of similar course integrations across the state. More broadly, it is situated within a larger effort to expand CT & computer science opportunities in K-12 education in Maryland through existing teacher preparation programs like that at UMD.

Our participants include teacher candidates in a math & science teaching methods course at Maryland (Paper 1), former students in this course (Paper 2), and instructors of similar courses across the state (Paper 3).

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Chapter 2: Module Implementation in a Mathematics and Science Methods Course

Introduction

A number of projects have designed learning experiences for CT in teacher education or PD. These include lectures within an educational psychology course (Yadav et al., 2014), after-school workshops for current teachers (Ketelhut et al., 2020), and redesigning an educational technology course to help teachers develop technological pedagogical content knowledge (Mouza et al., 2017), as well as other efforts.

This work builds upon these efforts by designing a module of lessons on CT that is designed to fit within a math and science methods course but could also be used within a different teacher education course in a similar program or with similar teachers. The lessons could also be used in an after-school workshop or set of workshops for in-service PD. One of the goals, discussed below, is to flip the traditional order of a CT introduction by having participants engage with CT activities before a formal introduction to how researchers organize knowledge about CT into domains, skills, and practices. This allows teacher candidates to develop experiential understanding of CT and then encourages them to see how research frameworks describe the skills and practices they noticed from these experiences.

As we study the effects of the module using video recordings from each lesson and artifacts created by teacher candidates for various assignments, we seek to answer the following research questions:

1. *How does an experience-first module on computational thinking shape teacher candidates' emerging computational thinking understandings?*
2. *After exploring this module, how do teacher candidates operationalize their own conceptualizations relative to existing computational thinking frameworks?*

Methods

Module Lessons

Here, we describe the module and underlying instructional approach before presenting results from a classroom implementation in the following section. The CT module is organized in a five-lesson sequence, occurring over a period of 5 weeks, with lessons moving from exploratory to more formal. This overall design takes inspiration from the Experience First, Formalize Later (Stats Medic, 2018) model in a novel application in the teacher education context. Experiential learning draws on the situated learning perspective, which holds that learning is a social process involving interaction with legitimate experiences in the learning subject (Lave & Wenger, 1991). Experience-based learning has been successfully used in pre-service teacher education before, in the context of cultural education (Gao, 2015). We also draw on Desimone's (2009) best practices for PD, which include participants having the chance to actively engage with the material, and ongoing, rather than isolated, sessions. This design will allow us to see how teacher candidates draw on existing knowledge to respond to discussion prompts and CT tasks. Each lesson is designed to last two hours, once a week for five weeks, meaning the entire sequence will take ten hours of class time. Participants were all fourteen teacher candidates enrolled in a mathematics and science methods course for prospective middle school (grades 6-8) math and science teachers. This course is situated in the fall of the students' Senior years, as they are simultaneously completing their part-time classroom internship experience before their full-time internship in the spring. At this point, students have taken much of their coursework and thus are relatively familiar with concepts in STEM education.

Lesson 1: CT Activities

The first lesson is intended as an exploratory introduction to CT. Teacher candidates are asked to pair up and work through two CT activities:

1. A Sphero robot programming task (Weintrop et al., 2022), in which participants use a mobile device connected to a rolling robot. They first use pre-existing code to roll the robot 1 meter, and then modify that code with a loop to measure the width of the classroom.
2. The Purple Bugs CT assessment (Jona et al., 2014), in which participants view a simulation of bugs and grass growing in a controlled environment and explore different outcomes when different

parameters are modified (for example, the speed at which grass grows or the amount of grass that the bugs eat).

These CT activities were selected because they have been used successfully to support STEM education in previous research.

For a take-home assignment, candidates are tasked with creating an "animated" Flipbook with notecards showing a ball dropping from the top of the page to the bottom. Finally, the candidates are asked to reflect on the flip book activity, as well as the two classroom activities and connections they see across the activities at this point. This will be followed up with a brainstorming task to gather candidates' initial impressions of CT in Lesson 2.

Lesson 2: Brainstorming Definitions of CT

The second lesson asks candidates to reflect on the first module's activities. The goal is to use the prior activities as a set of shared experiences that candidates can use to ground their emerging conceptualizations of what CT might be. The lesson begins with a small-group brainstorming session: each group is asked to generate a list of ideas about what CT is and what concepts and practices it might include. Following the brainstorming sessions, groups share their ideas with the class. During the whole-group discussion, the goal is to draw out and highlight the different emerging perspectives on CT shared by different candidates. The aim of this exercise is not to present a specific, concrete definition but instead to map out the landscape of potential concepts, practices, and ideas that might constitute CT.

The next activity is an introduction to Anotemos (Herbst et al., 2019), a video-tagging tool used to facilitate analysis and discussion of classroom video. For their homework, candidates are asked to review a classroom video of 4th-grade students engaged in a CT-rich mathematics activity. Specifically, they are asked to tag moments in a video when they think the student is doing or using computational thinking as the work on a Sphero robot challenge. The results of their tagging the video will serve as materials for the Lesson 3 activity.

Lesson 3: CT Frameworks and Relationships to Standards

This lesson begins with a review of participants' tags in the assigned video. First, the tags are made publicly visible so that the participants can all see each others' tags. Review of these tags proceeds in a Think-Pair-Share format: First, participants are asked to review the class's tags and, on their own, reflect on emerging patterns and if/how their coding did or did not cohere with their classmates'. The goal of this activity is to give candidates additional experience thinking about and identifying CT in a classroom context and to further develop their conceptualizations of what CT is (or might be).

Following this discussion, the class is introduced to two formal CT frameworks: the PRADA framework (Dong et al., 2019) and the CT in Math & Science Framework (Weintrop et al., 2016). Other academic conceptualizations of CT exist; however, these two frameworks are specifically aimed at organizing concepts in CT for integration into K-12 education. Concepts in CT are grouped and phrased in ways meant to be understandable and applicable for K-12 teachers. The emphasis of this module is not that teacher candidates walk away with academically correct understandings of CT according to either of these frameworks but rather to introduce some language and structure around what constitutes CT. To emphasize this view of the frameworks, the instructor leads a discussion asking candidates to situate their emerging ideas of CT relative to the frameworks, focusing explicitly on where there are differences between the two. Part of the effort here is to empower teachers to have their own ideas of CT independent of what specific frameworks state. Related to this, the instructor highlights how there is not a specific, universally agreed-upon definition for CT and that it remains a contested term.

Following the discussion of formal frameworks, participants are asked to compare CT to standards in their content area: the Common Core State Standards (CCSS) for future math teachers and the Next-Generation Science Standards (NGSS) for future science teachers. To facilitate this process, candidates are asked to reflect on how the disciplinary standards do and do not align with CT.

This lesson concludes by introducing the activity that is the focus of the remaining two lessons: integrating CT into a classroom lesson that the candidates will teach as part of their upcoming internship. To start this culminating activity, participants group up by discipline and review 2-3 lesson plans in their subject area to brainstorm potential ways to integrate CT into each lesson plan. For homework ahead of Lesson 4, the candidates are asked to integrate CT into a single lesson and bring it with them to the following class.

Lesson 4: Lesson Plan Review

The penultimate lesson begins with a review of the CT-integrated lesson plan modifications created as the weekly assignment from Lesson 3. Participants partner up (preferably, partners will both be from the same discipline) and share the lesson plan they modified, highlighting places where they integrated elements of CT into the lesson. After the partner discussion, participants rejoin as a whole class, to share insights from their discussions and identify emerging patterns and challenges they encountered.

Following the whole-class discussion, the class examines a CT-infused lesson plan from the Sphero.Math project (Weintrop et al., 2022). The goal is to have candidates analyze an exemplary CT-infused lesson as a way to identify effective strategies for integrating CT into existing lessons and further develop candidate knowledge around ways to integrate CT into the classroom. The class concludes with another class discussion around instructional strategies for integrating CT across the curriculum. Candidates are given the assignment of revising the CT-integrated lesson plans they created for this class ahead of the final lesson.

Lesson 5: Lesson Plan Presentations and Conclusions

The final lesson of the 5-lesson sequence is focused on candidates sharing the lessons they designed that integrate CT into their content area. Each candidate is given a chance to briefly present their lesson to the class, specifically highlighting what CT concepts/practices they are focusing on and how they are integrated alongside the disciplinary content goals or the lessons. After the presentations are complete, the instructor leads a summative discussion on the relationship between CT and disciplinary content in mathematics and science classrooms.

Participants

The five-lesson module was piloted in a pre-service middle school (Grades 6-8) math and science methods course offered at a large university in the Mid-Atlantic region of the United States. All fourteen teacher candidates participated in our study in the Fall 2022 implementation examined here.

Data Collected

A variety of data was collected across the five classes of the methods course (**Table 1**). Here, we briefly describe each data source that was analyzed for this work.

Lesson	**Video Recordings**	**Artifacts**	**Surveys**
1	Group work on CT activities		Pre-Assessment
2	Small group discussion on CT; Whole-class on CT	Brainstormed list on "What is CT?"; Anotemos tags	
3	Whole-class discussion of CT tags; Whole-class on CT frameworks; Discipline groups on Standards		

4	Partner discussions on lesson plans; Whole-class on lesson plans; Group work on Sphero lesson; Whole-class on revisions	CT Lesson Plan (1st draft)	
5	Lesson plan presentations; Whole-class concluding discussion	CT Lesson Plan (final draft)	Post-Assessment

Table 1. Summary of data collected throughout the implementation of the module.

Pre- and Post-Assessment Survey

Candidates completed a questionnaire (see **Appendix A**), including both Likert-scale responses and open-ended responses, that asked about their attitudes and understanding of CT, including whether they believe it can be integrated into their future classrooms (Yadav et al., 2014). The survey begins with an open-answer response question: "What is computational thinking, in your own words and to the best of your understanding?" This question was placed at the beginning of the survey to avoid participants' responses being skewed towards terms seen on the Likert items. This questionnaire served as a pre-assessment and post-assessment of these attitudes and the teacher candidates' knowledge of CT.

Video Recordings

All five lessons of the module were videotaped, including both whole-class discussions and grouped discussions and brainstorming sessions.

Candidate-Created Artifacts

Several artifacts were collected throughout the module as indicators of candidates' understanding of CT: a brainstormed list answering "What is CT?" from Week 2, Anotemos video tags from Week 3, and the draft and final lesson plans that the candidates submitted in Weeks 4 and 5.

Analysis Plan

Analysis of the video data and artifacts was conducted using techniques from both inductive and deductive coding approaches (Bingham & Witkowsky, 2021). We labeled passages in the data with codes generated both inductively and based on concepts and skills defined in previous academic work on CT and its domains (e.g., PRADA). For example, if a passage in a candidate's response was closely aligned with the previously defined concept of "decomposition," we used that for our code; however, we anticipated needing inductively-generated codes outside of those from previous research.

RQ1: Initial Knowledge

To answer the first question, *How does an experience-first module on CT shape teacher candidates' emerging CT understandings?*, we concentrated on initial expressions of ideas about CT (i.e., at the beginning of the module) as these were shaped by candidates' firsthand experiences with CT activities. We focus on the first two weeks of the module, during which candidates wrote their interpretations of what CT is on the pre-assessment survey (before they have experienced the activities) and brainstormed a list answering the question "What is CT?" with their small group (afterwards in Week 2).

We began with written responses to the pre-assessment and analyzed the text with an eye for concepts and skills that candidates associated with CT. One researcher generated a list of codes to describe the data. We then reviewed this list as a research team and confirmed that the descriptions of participants' written responses appropriately capture the data, allowing members of the team with varying perspectives to share their interpretations.

The next source of data comes from Week 2, in which candidates discussed "What is CT?" first in small groups and then as a class. The analysis followed a similar process to the analysis just discussed and was conducted on transcripts from the discussions. Again, one researcher took the lead on creating a list of codes to describe the commentary from the videos; these codes again covered both elements (e.g. concepts, skills) of CT, and how those elements are organized.

The final piece of data from the module for initial impressions was from the "What is CT?" brainstormed list, representing the final product of the discussion held in each small group. We reviewed the list as written by each group.

RQ2: Effects of the Experience First, Formalize Later Module

To answer the second research question, *After exploring this module, how do preservice teachers operationalize their own conceptualizations relative to existing*

CT frameworks?, we focused on the knowledge expressed over the latter half of the module and after its completion.

The first source of data came from Week 3, when disciplinary groups compare CT to disciplinary standards. Because we are explicitly asking candidates to organize knowledge through comparison, we anticipated that this would be a major moment of reorganization. We looked closely at these videos (one from the science group, one from the math group), attending to ways candidates expressed knowledge around CT and how they interacted with the frameworks presented. As in previous analyses, one member of the research team generated codes on a first pass, collectively reviewing with the rest of the team to confirm and modify codes.

The second source of data comes from Week 4, when candidates discussed with a partner and then the class their initial ideas for a CT-integrated lesson. Here, we paid close attention to what "domains of CT" candidates list to the discussion question, as well as how they distinguish CT from standards in their field. Again, we looked primarily for any changes in candidates' knowledge compared to the beginning of the course.

Results

In the results below, pseudonyms are used to protect participants' identities.

Initial Knowledge

The Week 1 pre-assessment survey question "How would you explain the concept of 'computational thinking'?" shed light on candidates' initial impressions before even experiencing the CT activities. Because candidates have had no preparation before this survey, this question measures their intuition about CT. Of the twelve analyzed candidate responses from the pre-assessment, seven distinct codes emerged (**Table 2**). While three gave a response coded as unfamiliar, the majority of the class gave a response indicating that they had a working concept for CT.

Code	**Number of Participants**	**Example Text**
Algorithms/Steps	6	"Thinking methodically, almost like thinking like a calculator (step by step)." -Laura
Unfamiliar	3	"I have no idea what it means." -Ben
Calculation	2	"I think it means thinking in terms of mathematically or doing math mentally." -Jessica
Reasoning & Logical Thinking	2	"Thinking with reason and in steps. Thinking this the purpose that one thought will lead to another and continue on until you reach a conclusion." -Callie
Analysis/Data Analysis	1	"A form of logical thinking where the subject would be able to analyze and form opinions based

		on the information provided or collected." -Lottie
Problem Solving	1	"To solve a problem using specific steps." -Taissa
Conceptualization/Abstraction	1	"To me, this means how do our brains conceptualize how to calculate things like distance, area, or time." -Travis

Table 2. Summary of codes used to label participant responses to the pre-assessment survey.

Six of the participants emphasized "steps," often framing CT as aligning with the concept of an algorithm. Akilah defined CT as "Thinking in a systematic step by step order," which strongly resembles the idea of a step-by-step procedure denoted by "algorithm." Callie, on the other hand, described CT as "Thinking with reason and in steps. Thinking… that one thought will lead to another and continue on until you reach a conclusion." While this response also includes "steps," it also incorporates the concept of a logical progression, rather than a series of steps in a task-oriented process, that is typically not included in the definition of an algorithm. This focus on reasoning was shared by another participant, Lottie, who wrote, "I hypothesize that it would be a form of logical thinking where the subject would be able to analyze and form opinions based on the information provided or collected." Lottie did not include any mention of step-by-step procedures but does combine her idea of "logical thinking" with some form of analysis, of "information provided or collected" or perhaps data. Another use of "steps" comes in Simone's response, who wrote, "The way you think is based on a process like there are steps like the scientific method" which pulls in the idea of the scientific methods as a way of grounding her interpretation of CT. In this response, we start to see a connection to disciplinary thinking that will become a focus over the course of the lessons. These connections to different disciplinary ideas like the scientific method and logical progression to a conclusion are all connected through the same word, "steps." Though this term is closely tied to the CT concept of an algorithm, when used as a bridge to the different disciplines, it takes on a different meaning and loses the connection to algorithms.

Of the final two responses, both discussed calculation (either mental math or "how our brains conceptualize how to calculate things like distance, area, or time"). Between these and comments involving the scientific method and logical reasoning, we see that candidates' conceptions of CT are largely grounded in ideas from their respective disciplines.

Our predominant source of answering RQ1, *How does an experience-first module on CT shape teacher candidates' emerging CT understandings?,* comes from Week 2. In this lesson, candidates are again prompted to share what they think CT is by brainstorming lists of what the concept might include. As part of this activity, participants created Google Jamboards, brainstorming pages where participants can add drawings, text, images, or sticky notes, to record their thoughts before presenting to the class. These offer insight into how candidates are conceptualizing CT after their initial impression from the activities in Lesson 1. Two example Jamboard slides are presented below (Figures 1 and 2).

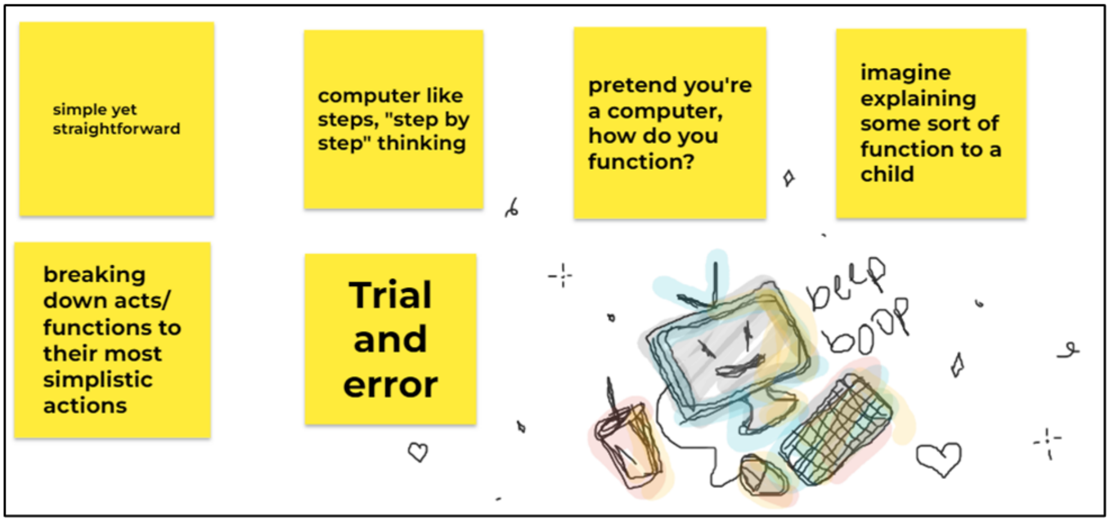

Figure 1. The brainstorming Jamboard created by the group of Akilah and Callie.

Figure 1 shows Akilah and Callie's Jamboard that articulates several ideas about CT. We labeled this slide with several codes reflecting the content of different notes: "Algorithms/Steps" for the post-it on step-by-step thinking, "Thinking Like a Computer" for the note on "pretend you're a computer, how do you function?" (as well as the accompanying artistic representation of a computer saying "beep boop," which Akilah drew using her tablet and a digital stylus), "Simplicity/Clarity" for the notes "simple yet straightforward," and "imagine explaining some sort of function to a child," "Decomposition" for the note on breaking down acts and functions, and "Trial and Error" for the corresponding note.

The relationship between these codes was clarified by what Akilah and Callie contributed to the class discussion; Akilah discussed including the drawing of a computer because computational thinking is:

> *"very computer-like, hence the computer… If you were pretending to be a computer, like, how do you function? Like, how do you write the steps down? Kind of like thinking about how like, when you're coding, there's like a step-by-step… Like, when you're trying to make something happen, like, you write all the little steps to it. So it's like, it's simple, but it's super straightforward… we also talked about like, what if you're trying to describe something, explain some sort of function to a child, like, you would really have to, like, break it down step-by-step so that they would understand it."*

Here, we see a connection between several pieces of knowledge. First, Akilah connects the notion of "computer-like thinking" concretely to two other ideas: coding, and through coding, writing well-specified algorithms with steps and procedures. The idea of specifying algorithms is also linked to the concept of simplicity, both explicitly and using the allegory of explaining something "to a child," in which she notes it is necessary to "break things down" (which we deem close enough to the concept of Decomposition, as defined by the PRADA framework, to label as such).

These connections were also brought up by another group. Laura and Simone, in describing their brainstorm, shared:

> *"So for both of us, we like, really liked the term you used algorithm, because we both were thinking like, computational thinking, like computer like, and then I like, kind of brought it back to the Sphero robot things where it was like, it almost felt like coding on Scratch. And like, I always think of coding as very, like, step-by-step thinking. And that also relates me back to, like, an algorithm."*

Again, the idea of an algorithm is linked to coding. Further, when responding to press from the instructor on what "computer-like" meant, Laura also talked about how coding a computer involves very small, specific functions:

> *"They do specific things if you tell them to do it. You know, like you code a computer in a way- when you use like, a keyboard, like backspace when you type, or like, when you're typing something, you're telling it to show the image of the letters on the screen. So I think like, it's very much like you tell someone to do something in directions, and then they do it back. So it's like very, it's step-by-step algorithm. And like, it'll give you that result with that input."*

Here, Laura again mentions the idea of an algorithm and connects it to coding, and through coding to an allusion of specific functions governing small actions within a computer's overall programming.

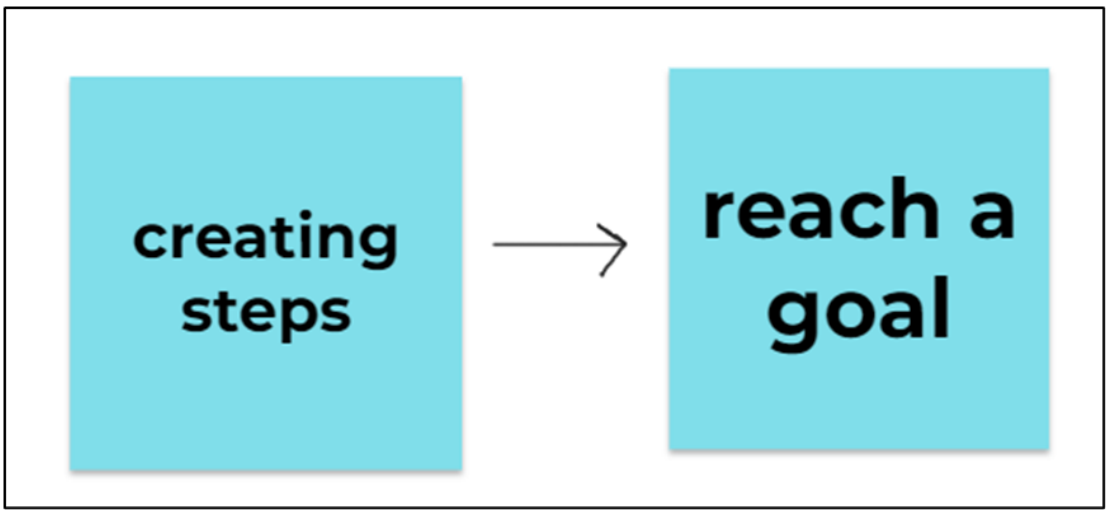

Figure 2. The brainstorming Jamboard created by the group of Ben and Lottie.

Ben and Lottie explicitly showed a connection between two concepts in their Jamboard slide (Figure 2), connecting "creating steps" with "reach a goal" via an arrow. We interpreted this link to mean that creating steps is done in the service, or for the purpose of, achieving some goal. Ben's commentary supports this interpretation as he described how in each activity, we created steps in service of a larger goal:

> *"For the ball rolling around like you had to create, like, the, the coding steps or whatever. And then our goal was to reach... The goal we're reaching was to see how wide the room was or whatever. And then for the ... Oh, yeah, so the bugs, it was like, we were creating steps to see like, if we change certain things like, what happened to the boat, like we were changing, like, how much water the plants got, or whatever, like changing the drought or whatever. And then we were trying to see how it affects the end goal and things like that. And then for the flipbook, it was kind of the same way, we're creating steps like reading the flip of the pages to see what it would look like."*

In each activity, Ben sees some form of "creating steps" that is in service of some larger end. With the Sphero robot, he saw this as coding a procedure for the robot to follow to measure the room. For the Purple Bugs activity, he saw this as changing the parameters of the simulation to get a different result. For the flipbook, he saw the creation of each page as a step in service of the overall animation. In each case, there are smaller steps (reminiscent of Decomposition), but also a focus on an end goal or product. In Ben's account, CT is creating (or perhaps modifying) steps to produce something, whether a measurement of a room, a simulation of an ecosystem, or an animated flipbook.

Changing Knowledge

To answer RQ2, *After exploring this module, how do preservice teachers operationalize their own conceptualizations relative to existing CT frameworks?*, we looked at data from later in the module. In the third lesson of the module, candidates are presented with two CT frameworks: the PRADA framework (Dong et al., 2019) and the CT in Math and Science Taxonomy (Weintrop et al., 2016). Participants took quickly to the new academic frameworks, noting mostly similarities between the frameworks and ideas they had already discussed about CT. For example, Jessica described CT as an "umbrella" described by their previous ideas that also included the domains and practices in the frameworks:

> *"The stuff that we already identified in the Jamboard are things that are mentioned here: observing, trial and error… all this stuff is under the umbrella of CT. So it's not like we're ignoring- we know what CT is, we're just putting more concrete, like, definitions to add to our understanding."*

Jessica had previously focused heavily on trial and error as a key element of CT. In Week 2, she described CT as "using our experiences and a trial and error kind of process," listing examples from each of the Week 1 CT activities:

> *"And then as we were like, in the class we had tested, which works and what doesn't and using those experiences to be like: Okay, well, how far do you think it has to go in order to measure like, the distance of the block? Or like with the Purple Bug thingy? Like, adjusting the amount of drought or how much grass decreased during the drought and how that affects like, the bug population making predictions based on like, oh, like, if there are less grass [tiles] that means more bugs will die because it- there's no food, etc. And then also like the trial, full trial and error process with kind of like, an animated flipbook, where we're kind of like, okay, well if it does- didn't work this way, drawing that way doesn't work, then like, how can we make our instructions more specific?"*

Jessica sees this trial and error process in both frameworks. She sees it as fitting with "Algorithms" and "Decomposition" on the PRADA side, while fitting into "Systems Thinking" on the Taxonomy side. For her, the introduction of the frameworks represents a shift in terminology. She does not see the frameworks as offering new ideas about CT; rather, they merely offer new ways to talk about existing ideas.

Laura, in contrast, describes changes in her thinking about CT prompted directly by the frameworks:

> *"When I was doing the Jamboard, thinking about what computational thinking was after we did, like, the Sphero and everything, I very much focused on the algorithms part. I really thought, like, that is computational thinking. And now that I'm seeing the rest of PRADA, like all the other things, I can see how there's things that we were doing that would fit into, maybe, this definition of computational thinking."*

In contrast to Jessica's relatively minor, vocabulary-centric reconceptualization of CT, Laura's realization seems to be a deeper adjustment. Rather than seeing CT as defined solely by algorithms, she has reorganized her understanding so that algorithms are only one of several ideas under the CT umbrella. This change, then, not only adjusts the pieces of knowledge she associates with CT (based on her mention of PRADA, we assume that she is now including Pattern Recognition, Decomposition, and Abstraction) but also the reorganization of a previous piece of knowledge as now just one domain among four.

As part of the summative activity for the CT module, 12 lesson plans were submitted and analyzed. The topics of these lessons, and the CT domains or practices integrated into each, are summarized in Table 3.

Author	Lesson Topic	CT Domains/Practices
Mari	Ratios & Proportions	Abstraction, Decomposition
Travis	Area of Parallelograms	Decomposition
Shauna	Climate Change and Natural Hazards	Pattern Recognition, Analyzing and Visualizing Data, Modeling & Simulation Practices
Lottie	Modeling Linear Relationships	Pattern Recognition
Natalie	Air Fronts & Weather	Pattern Recognition, Understanding the Relationships in a System, Defining Systems and Managing Complexity, Analyzing and Visualizing Data
Taissa	Carbon Footprint	Pattern Recognition, Abstraction, Decomposition, Algorithms
Simone	Areas of Parallelograms	Pattern Recognition, Abstraction, Algorithms
Jeff	Asexual and Sexual Reproduction	Computational Model, Abstraction, Collecting Data, Analyzing Data

Misty	Charts and Graphs to Express Relationships Between Data	Data Practices, Pattern Recognition, Algorithms
Callie	Displaying a Data Distribution	Collecting Data
Akilah	Scale Drawings of Gardens and Area	Decomposition, Modeling and Simulation, Assessing Different Approaches/Solutions
Laura	Linear Relationships: Car Speed and Skid Marks	Assessing Different Approaches/Solutions, Analyzing and Visualizing Data, Troubleshooting/Debugging, Thinking in Levels, Defining Systems & Complexity, Using & Designing a Computational Model

Table 3. CT domains/practices (from PRADA and the CT in M/S Taxonomy) integrated into lesson plans.

Candidates' lesson plans integrated a wide variety of CT domains and practices, drawn from both PRADA and the CT in Math and Science Taxonomy. Across all lesson plans, we see four domains from PRADA and eleven practices from the Taxonomy. Compared to the seven codes we found in candidates' initial commentary on CT, this demonstrates that they are including many more ideas in their conception of CT. Most candidates' lesson plans also included multiple domains or practices, indicating a shift away from a view of CT as a singular concept, as seen in many responses to the initial survey.

Discussion

This multi-lesson module offers teacher candidates exposure to CT through many different lenses: first through the hands-on experience of completing a series of CT activities, second through their own interpretations of those activities, third through academic frameworks, and finally through the act of creating a lesson plan that includes CT practices and ideas. Each of these also provides an opportunity for researchers to gauge participant understanding as they progress through the module.

As shown above, candidates brought prior knowledge and experiences to the module that served as a means for grounding their emerging understanding of CT. This largely focused on algorithms and “step-by-step” thinking, with some mention of calculations and the scientific method. These latter points are interesting as it shows candidates’ proclivity for trying to situate CT within disciplinary contexts. By the end of the module, candidates were using a wide array of ideas that show up across CT frameworks like PRADA and the CT in Math and Science Taxonomy. This suggests the productivity of including opportunities for learner-generated definitions (in this case, through hands-on activities and discussion) before exposure to formalized academic definitions.

Experience First, Formalize Later and CT

A central design decision for this work is the implementation of the Experience First, Formalize Later approach (StatsMedic, 2018) to introduce teacher candidates to CT. This is a novel approach in CT teacher education, where other efforts have been structured as guest lectures (Yadav, 2014) or PD workshops (Ketelhut et al., 2020). The decision to use the experience-first structure was motivated by prior research that found math and science teacher candidates, when being introduced to CT through frameworks, would rely heavily on specific language and ideas that aligned with their disciplinary knowledge (Walton & Walkoe, 2021). For example, after being introduced to the PRADA framework, the authors documented how a math teacher clung tightly to Pattern Recognition as a way to interpret CT in a mathematics context given the overlaps the teacher saw. The result was a rather narrow conceptualization of CT. In contrast, with the Experience First, Formalize Later approach presented above, candidates are given hands-on CT experiences and are provided the opportunity to create their own ideas about CT based on these experiences. This allows candidates to develop their own conceptualization of CT before being introduced to formalized definitions of CT. This approach is particularly generative given the existence of several CT frameworks and ways they cohere and differ as it relates to specific concepts and practices (Shute et al., 2017).

Limitations and Future Work

The goal of this work was to document the experience and outcomes of teacher candidates being introduced to CT via an Experience First, Formalize Later module integrated into a pre-service teacher methods course. While we think the module was successful and the accompanying study was able to document productive CT reasoning from the candidates, this study is not without its limitations that we hope to address with future work. First, this sample is relatively small and all of the candidates are in the same program, meaning they all have shared educational experiences through the program they are enrolled in and live in the same geographical region. While this does not undermine what is presented above, it points the way toward future work to explore how candidates from different regions and different sets of prior knowledge would engage with the presented module. Another limitation comes from the specific activities and technologies used in the CT module. Does Sphero foreground specific CT practices? Does the Purple Bugs activity make certain CT concepts more salient? Likewise, we chose two CT frameworks to focus on but there are others that could have been used (e.g. Brennan & Resnick's (2012) framework of CT as concepts, practices, and perspectives). All of these decisions directly influence the results of the paper and it is not clear how findings might have differed with a different set of activities or frameworks. Exploring this relationship is a second possible avenue of future work. Finally, our positionality as CT researchers and math educators shaped the lens we brought to this work. Further, the fact that we designed the module, led the class sessions where candidates engaged in the module, and conducted the analysis presents a situation where we are not objective outsiders conducting the analysis but instead are deeply invested in the results. While we do not think this undermines the findings as the data presented above speak for itself, this does suggest this is a context where recruiting others to extend this work and use the module in other university environments would be particularly generative.

Conclusions and Future Directions

This work sought to explore teacher candidates' emerging conceptualizations of CT through the use of a 5-lesson module embedded within an existing elementary math and science pre-service methods course. Through engaging with a series of CT activities and discussions, candidates' understanding of what CT is (or could be) expanded. In structuring the lessons in a way that first provided hands-on experience with CT-infused activities before moving to formalized definitions, the sequencing sought to help candidates ground their emerging understanding of CT in ways that helped them build connections with prior knowledge and experience. In particular, activities that allowed candidates to engage with CT and then collaboratively reflect on those experiences and identify commonalities across these experiences served as a useful context to develop foundational intuitions related to CT before introducing them to formalized definitions and terminology. In doing so, this approach helped candidates develop flexible CT definitions that can help them infuse CT across their classrooms in a diversity of ways, as seen in the breadth of CT and disciplinary concepts included across the final projects (Table 3). Collectively, this work contributes to the growing literature on ways to introduce future teachers to CT and showcases candidates' abilities to identify CT, its potential connections to disciplinary content, and connect their prior knowledge and hands-on CT experiences to formalized definitions that can serve as a foundation for infusing CT into their future teaching.

Citations

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Chapter 3: Use of CT Knowledge as Classroom Teachers

Introduction

Previous research on CT and teachers has covered a wide range of outcomes, in increasingly practical applications from beliefs about CT to knowledge about its domains to knowledge for teaching. Some studies on teachers and CT focused on attitudes and beliefs. For example, Yeni & colleagues (2021) asked participating teachers what they thought the benefits of CT integrations were for students and teachers, and their attitudes towards future usage, and Garvin & colleagues (2019) asked participating teachers about their comfort integrating CT in the classroom.

Other work has examined teachers' knowledge about CT, both generally and pedagogically. Garvin & colleagues (2019) studied teachers' definitions of CT. Some teachers gave answers that were coded as Using a Computer (deemed an insufficient definition of CT in the context of the study), such as "knowing how to use computers" and "computer's way of solving problems," while others described a recognizable subdomain of CT based on academic frameworks, like decomposition ("break the problem up into smaller steps"), and still others gave "expert"-level definitions such as "computational thinking is made up of 4 components that do not all need to be present for it to be considered CT. The components (decomposition, abstraction, patterns, and algorithm) are used to solve problems," (p. 901). Past the surface-level analysis of the completeness or accuracy of teachers' responses, the researchers also delved into which components of CT, such as decomposition, teachers emphasized and in what proportion of definitions those components were present. Focusing on teachers' initial preconceptions of CT (i.e. before formal learning on the topic), Cabrera (2019) found that teachers often conflated CT with broader definitions like "technology integration," "CS/Programming," "simply a problem-solving strategy," or "thinking like a computer." He notes that these preconceptions may not support the task of effectively integrating CT within the classroom; compounding this, teachers often also hold preconceptions of CT as "belonging outside K-12" or a "difficult topic to learn," (p. 312). Another study found that among teachers, there is confusion over technical "jargon" in CT (Munasinghe et al., 2021). Pedagogical content knowledge (Shulman, 1986) for teaching CT is a related topic of interest for researchers: Yeni & colleagues (2021) explored teachers' knowledge of goals and objectives, knowledge of student understanding, instructional strategies, and means of assessment within the domain of CT. A teacher may possess valuable understanding of what CT is, but without the pedagogical content knowledge to teach it in the classroom, that understanding may not be effectively used and will likely not be passed on to students.

We are particularly interested in the latter line of research because, while there are a multitude of available resources to learn about CT, there are many less resources available to teachers looking to integrate CT in their classrooms. Training resources for teachers tend to be limited to teacher preparation programs rather than in-service professional development, and are typically available due to the proximity of a local expert in the intersection of CT and education (e.g., Yadav et al., 2014). Assessments of Yadav's implementations and related work focus on whether they are effective in changing knowledge about CT; with this study, we seek to understand how teachers use CT in a practical classroom exercise, to understand how they use their understanding of CT in practice. We move one step closer to how teachers use CT in the classroom by observing our subject teachers while they plan a CT-integrated lesson; this moves beyond knowledge taken up or held about CT to the knowledge that is used in practice. While lesson planning, we analyze how they use their knowledge about CT actively, as opposed to what inert knowledge they may hold. In doing so, we focus on the research question:

How do teachers use knowledge about computational thinking in practice when planning an integrated lesson for their classroom?

Methods

Pilot Study Design

A pilot study with a single participant from the Fall 2021 implementation of our module led us to develop a theory of two CT "frames," or operational ways of thinking about CT (Hammer et al., 2005) – a "student" frame as she remembered her learning experiences in the module, and a distinct "teacher" frame as she planned a lesson for her class – that will be further examined in the current study. Our previous focal participant, who we will refer to as Rebecca, was a college Senior at the time of the study, enrolled in the undergraduate teacher preparation program in middle school mathematics. At the time of the clinical interview, she was teaching eighth grade mathematics as her full-time internship - in her words, "two regular Math 8 classes, and the other two are co-taught Math 8 Special Ed classes."

In the previous semester, Rebecca – with the rest of her cohort – had participated in a five-lesson module on CT as part of her middle school math & science methods course. This module introduced CT in an "Experience First, Formalize Later" (Stats Medic, 2018; Gao, 2015) manner. Undergraduate teacher candidates first participated in CT activities themselves, then brainstormed lists of ideas to define CT, and finally compared these lists to existing academic frameworks on the organization of CT concepts (e.g. Dong et al., 2019; Weintrop et al., 2016). The module included an emphasis on how concepts in CT compared and contrasted with concepts in math and science standards (i.e. CCSS-M, NGSS). The lessons from this CT module were recorded, and we used these recordings to give us some baseline terminology for how Rebecca talked about CT during the course.

In the semester after this module, Rebecca met with us across three interviews to plan, execute, and reflect on a lesson plan modified to include CT. These interviews were purposefully left open-ended: we allowed Rebecca to determine a lesson that seemed fitting for a CT integration, and the details of how to integrate CT, as we thought leaving these choices to her would draw out more of her conceptions of CT and where it would be best used.

We reviewed the transcripts of our interviews with Rebecca and, first, described different segments of her responses using inductive coding (Thomas, 2003). What we mean by “inductive coding” is that codes were generated in the process of describing the data, rather than being pre-existing; we did not impose pre-existing terms from CT research or other studies because we did not want to assume that Rebecca’s understanding would fit with these conceptions of CT. Once codes were generated to summarize different segments of text, we looked for connections and similarities between codes. We organized these into sub-themes, and drew some of these sub-themes together into three larger themes: Class Suitability, Doing CT as a Teacher, and Doing CT as a Learner as we will discuss in the next section. Again, effort was taken to leave Rebecca’s intent intact as much as possible, to preserve the meaning of her responses as she seemed to intend them (Fereday & Muir-Cochrane, 2006; Gibbs, 2007), rather than trying to fit them into pre-existing organizations of CT.

Follow-up Interview Design

This study lends merit to the study of how teachers use their knowledge about CT in practice, separately from their understanding of CT as learned from instruction in their coursework or professional development. Our interviews with one teacher intern indicate that she does not draw on the same resources to plan CT-integrated instruction as the resources she learned from previous lessons on the subject. To ensure that teachers are fully prepared not only to understand CT but to use it effectively in the classroom, we must explore ways this may be supported across STEM teachers, and if so, consider how to modify instruction on CT to ensure teachers can use that knowledge in practice.

Our natural next step is an exploratory study to see how other teachers use knowledge about CT in lesson planning, and to see whether the themes noticed in Rebecca's responses are present in other teachers' responses. To this end, we reached out to teachers who previously participated in the CT course module within their mathematics & science methods course and found a second focal participant, pseudonymized here as Eileen. At the time of the interviews, Eileen was a middle school math teacher teaching grade 6 math. She described her class preps as "on grade-level math 6 and also accelerated math 6."

To examine CT used in practice, we added one activity on top of the previous lesson-planning we did with Rebecca. This new activity will consist of Eileen watching classroom video of a lesson where students are doing CT in some capacity in our first interview. We asked Eileen to identify moments where she thought students were "doing CT" and further to comment describing what the students are doing.

Following this activity, we introduced the lesson-planning activity. In the first interview, Eileen identified a lesson in which they would like to introduce CT. In the second interview, Eileen brought a draft of her CT-integrated lesson plan to review with us. In our conversation, we asked her what activities she chose to integrate CT into this lesson, why she chose those activities, what skills and practices she thinks those activities elicit, and why she chose to focus on those skills and practices for this lesson. Through this, we hoped to see her understanding of CT's use in the classroom, and particularly how it can support instruction in her discipline, mathematics.

In the third interview, we will review Eileen's experience teaching the CT-integrated lesson. Our questioning will focus on what CT skills and practices the teacher saw students engaging in during this lesson, and comparing this to the target goals of the lesson as planned. Through this evaluation of the lesson, we hope to see more examples of activity Eileen describes as "CT" as enacted by students, to further help us understand how they conceptualize CT in practice.

Findings

Rebecca

As we coded the data, three major themes emerged. First, Rebecca sometimes talks about *Class Suitability* for a CT lesson, including characteristics of the students in the class and logistics of the schedule or other factors that make it a more or less appropriate class for a CT-integrated lesson. Second, she talks about *Doing CT as a Teacher*, or practices that she associates with leading the class through a CT activity, or elements included in that activity. Finally, we saw the theme *Doing CT as a Learner*, for codes mostly associated with Rebecca's own experience learning about CT. We discuss each of these themes, and the codes within them, below.

Class Suitability

Rebecca often talks about how to decide which class period to use for a CT-integrated lesson. This category of codes about CT are pragmatic and often tied directly to the practice of unit planning (e.g., thinking about where in a unit a CT activity would fit in).

The first sub-theme in Class Suitability is *Student Characteristics*, focusing mainly on the abilities of students in the class and how Rebecca sees this affecting the suitability of a CT lesson. An early example of this sub-theme is when she explains the class she has chosen for the integration:

> *"And the class I wanted to focus on for this particular CT, it's interesting, because I was looking, I've been looking at the school data all year long. And I have there's like, five kids from just assessment, all this data that I've seen that, in my opinion, and in my mentor's opinion should have been in algebra, they shouldn't have been in Math 8 because there's, they just pick up on things naturally, very, like I don't know how to say, intuitively, they just end up going really quickly. And I feel bad because we, we kind of have to like cater to what- where everybody is. And the majority of the students does take a lot more- a lot longer. But... But yeah, and so, it's kind of like I have to do kind of two lesson plans for one class so, so that other kids who are a lot faster, have something to do once they're done."*

Rebecca does not specify exactly why the split-level nature of this class makes it a good target for a CT lesson here, but it is clearly a salient aspect for her when considering the class she wants to choose. Based on her words, we can speculate that a CT lesson might fill the niche of giving students who move more quickly through material an additional challenge or otherwise make it so that students at different levels can work on one activity at the same pace.

We also saw this sub-theme emerge when Rebecca discussed how much scaffolding students might need to begin their CT investigation. Again, she talks about characteristics of the class:

> *"And it's- um, by now they've- they know how to graph and they know how to use substitution. We haven't done elimination with them yet... I think one or two students... we differentiate a little bit because a couple students are really ahead, they like zoom past things. And so they may have knowledge of elimination. So in their group, they may present the idea that we can solve this through elimination, but I don't know how that will probably work out."*

At this point in the planning, Rebecca has chosen a lesson in her Systems of Equations unit to integrate CT into. Here, the discussion of student characteristics is more specific: some of her students move quickly, and in doing so may have encountered the elimination method of solving systems, while others may not have. While Rebecca sounds unsure about exactly how this will play out, she does not seem worried about it, implying that a CT-integrated lesson seems to be a good fit for these students of varying levels. (She also alludes to a group work structure and the freedom to respond to a task with multiple methods, which we will discuss in the following section).

Along with characteristics of the students in the class, Rebecca sometimes mentioned aspects of the class meeting schedule itself as factors in her decision. Below, she mulls over the choice between Systems of Equations (the unit she is finishing) and Line of Best Fit (the unit she is about to start).

> So if I were to be honest, it would be a tight situation… Oh, yeah, …to the 5th, totally fine. But that being said, I don't this that last week of line of best fit or scatterplot, it might just be that it gets pushed past the 5th or 6th just- just the way that things are. Because if you look on the 25th, we have a

> common assessment, which is something that kids have to do that a- testing wise. And what happens is not all kids show up and all kids have to take it by a certain date. So it's one of those things where like, I think we could do line of best fit, I feel like it might get put down, even then, even then, because I see my first period, twice during homeroom.

Rebecca's discussion here focuses on a common assessment potentially conflicting with the early dates of the Line of Best Fit unit, or pushing this unit back. She ultimately concludes that putting the lesson at the end of Systems of Equations will be a better fit. Later, we will see that in addition to this calendar conflict, Rebecca sees CT-integrated lessons as fitting better into the later end of a unit rather than the beginning, which may be implied in her reluctance to schedule the lesson early in the Line of Best Fit unit.

In general, the *Class Logistics* theme was an unexpected finding because, while these scheduling and student-level considerations are of course constantly necessary for a classroom teacher, we did not talk about CT lesson planning this way in our CT module, and these considerations did not come up in class discussions. Instead, this line of thinking seems to come directly from Rebecca's professional experience as a teacher intern, a trend we also notice in the theme *Doing CT as a Teacher*.

Doing CT as a Teacher

This theme consisted of practices Rebecca associated with leading a CT lesson as a teacher. *Doing CT as a Teacher* included a multitude of sub-themes, which we summarize in **Table 1** below. In contrast to the *Class Logistics* theme, this theme was more specific to particular activities or strategies used within a class period, rather than the selection of a class and class period for CT integration.

Table 1. The sub-themes observed in *Doing CT as a Teacher*, with a representative segment from Rebecca's transcript as an example of each.

Sub-Theme	**Example**
Culminating Activity/ Higher Level	"I think it would have- would have just been better just to do a more challenging activity with systems, because they have been working on it slowly to a point where they can try to make those connections. Versus if I- if I just jumped in with something new, they would- they'd really just be put off by it."
Student Choice/ "Figure It Out"	"There were like different approaches you could take, which is why some students graph, or why some students solve out the slope formula to find...?"
Computational Tools	"Computational tools, calculators, they used like...not the graphing kind, but also not the four function. There's like a middle ground between... [Scientific?] Yeah, okay, why use a scientific calculator only for the groups that decided to actually solve out for the slope formula, like y2 - y1? [What other tools did they use?] I don't... rulers? Does rulers count?"
Group Work	"And they were working in small groups. And it was random groups, too. It was groups that they weren't used to. So it's another factor of them- of them- us having them work with other students that they may not know well, so well."
Logical Thinking & Defending Claims	"So it says if we plot the points A, B, and C, they look like they might be on the same straight line, but looks can be deceptive. How can we be sure? So they had to prove to us whether or not the statement that they were- that we had put on the board was true. And they had to defend that claim."
Breaking a Process into Small Steps	"And then like, what are the steps for you to do that? If you have to graph it? How do you graph and it's like, okay, I have to like, draw like, the coordinates. I have to like, plot the points. And then I have to see."

Rebecca connects these ideas to CT in indirect fashion: she often replies to questions about seeing CT in the classroom, or how CT could be incorporated, by talking about one of these sub-themes. For example, when asked about instances of CT she has seen in her classroom, she responds, "Yeah. So... because we were trying to catch up on curriculum so fast that we didn't have- we didn't give my students a lot of chances to group work," then elaborating on one example where they did:

> *"We hadn't- we hadn't taught- students hadn't made the connection yet that points in a line have the same slope, and we wanted them to get there- there by itself. So we had so we had this like, prompt about like, how do you know if these lines- or like- something like that, I forget, but the thing of it is, it was something that they had to work together with a group, try to break it down and figure out what do I know about slope? What do I know about these lines? What do I know about these two points that are on these lines? We told them, they can figure out whatever- we gave him like these huge posters that they had to like- some, some kids graphed it out, some kids found a slope, some kids like wrote out sentences... But they had to like break it down. And throughout that activity, my mentor and I, every 15 minutes, we would give them hints so that where they were would lead them to it. It was like a lot of problem solving. And they were working in small groups. And it was random groups, too… groups that they weren't used to."*

In responding to the question about CT, Rebecca's first instinct is to report on group work, implying that she sees an association between CT activities and group work. A majority of the activities in the CT module were done in groups, which may be a possible explanation for this mental link. However, it is primarily a pragmatic element of a CT activity, something a teacher might need to consider when preparing or planning the lesson, and less related to the content within the lesson. Contained within this passage is another practical element of this lesson activity, which we tagged with the sub-theme *Student Choice/"Figure It Out"*: students are not given all the information for a task, nor are they told to solve the problem a certain way. Rebecca even states that she and her mentor teacher had not taught the concept that was a desired outcome of the lesson, and the activity seems to be organized in such a fashion that students will discover this concept on their own. Students can also use different techniques to solve the problem as proposed. We see this several other times when she is talking about CT. The first is when she proposes an activity to integrate CT into, which involves solving a system of equations. Rebecca states that students could use several different methods to get to a solution:

> *"They know how to graph and they know how to use substitution. We haven't done elimination with them yet... I think one or two students... we differentiate a little bit because a couple students are really ahead, they like zoom past things. And so they may have knowledge of elimination. So in their group, they may present the idea that we can solve this through elimination, but I don't know how that will probably work out."*

There is a clear flexibility to this task which, in Rebecca's mind, appears to make it more suitable for CT integration. Not only does Rebecca support students using different solution methods that they've learned from class, she even acknowledges that some students may bring in solution methods they learned outside of class to share with their group.

The sub-theme *Culminating Activity/Higher Level* was used to describe cases where Rebecca directly expressed, or indirectly implied, that CT lessons are best done when students have had some previous learning on the topic to be covered and can use that knowledge flexibly to discover a goal of a higher level. For example, when she mentions a CT-style activity that her class has already done, she notes that they already knew how to use the slope formula, and also knew how to graph points on a coordinate plane. In that lesson, students were asked to prove that three points were collinear, potentially drawing on that previous learning to reach a higher end. In the lesson to be enacted, Rebecca will ask students to solve a system of equations to find the costs of shirts and pants: “In this scenario, they're holding the same shirt and the same pants which cost the same obviously, they just have to determine what the cost of the shirt and the pants are based on the different number of items and the different total costs. So they kind of have to- they haven't- to be honest, we haven't worked too much on word problems with systems of equations yet, so this will be something new, but it's still within systems.” She notes that students have already learned to graph, and to solve systems by substitution (and that some of her faster-paced students may be familiar with elimination as well). This activity serves somewhat like a capstone task to bring together different ideas from the Systems of Equations unit and allow students to use them flexibly to tackle a new task of a higher level (in this case, a word problem).

Two further sub-themes, *Breaking a Process into Small Steps* and *Logical Thinking & Defending Claims*, are sporadically mentioned by Rebecca throughout her transcripts. These are also sub-themes that we will mention in the following section on *Doing CT as a Learner*. However, we have included these sub-themes separately here because Rebecca brings them up in the context of teaching the class, not solving the task. For example, when talking about her previous CT-style lesson, she mentions asking students, “And it was like, well, how do you- how are you going to defend that claim that you just made? It was a lot of, like, those things I need you to prove to me." As she brings up these sub-themes in this context, they have more to do with what Rebecca as a teacher is asking students to do than what they are actually doing. In other words, they factor into her planning for the activity more than what happens during the activity.

This way of thinking about CT is closely tied to the enactment of a lesson – group work, higher-level activities that act as capstones to previous learning, intentionally offering less-than-complete information about how to solve a problem, acceptance of flexibility with the methods students may choose to use to solve it, and thinking about what kinds of activities to ask students to do. These elements all seem tied to the things a teacher might need to think about when planning or enacting a lesson that infuses CT.

Doing CT as a Learner

Some of Rebecca's response patterns seemed less tied to lesson planning and more tied to her memories of CT activities in the module as taught in the fall. In part of the interview, she is asked what she remembers from the module. She lists two activities: a programming activity in which she and her group used a rolling Sphero robot to measure a room using a short program, and a mock programming activity where they wrote a "program" for a fellow student to follow to walk across the room:

> *"I remember the activity just trying to figure out, one how the Sphero works and how to program it, which I think was a lot of fun, which I think if I were like a younger student trying to figure out like what like I don't know computer science or coding is it'd be something fun to figure out, because you're making it work. And I also remember, before we did the actual Sphero, I vividly*

remember just [fellow student], we were programming her to walk and move in certain directions and think about every single step that she had to take, even like. So I just remember that vividly."

This segment exemplifies how Rebecca links ideas about doing CT from the perspective of a learner back to specific learning activities she participated in during the module. We tagged the above with sub-themes *Figure It Out/Making It Work*, a learner-perspective variation of the sub-theme *Student Choice/"Figure It Out"* that fell under the *Doing CT as a Teacher* theme, and *Breaking a Process into Small Steps*, a learner-perspective variation of the *Teacher* sub-theme of the same name. In both these cases, the concept Rebecca discusses is not tied to what the activity specifically asked them to do, but what she as a learner found she had to do to complete the activity. The final sub-theme, *Logical Thinking & Defending Claims*, is something that Rebecca only discusses abstractly with respect to her own experience, saying she recognizes it from a list of CT elements that her group brainstormed during the module: "Also the last part, use logic to solve problems."

Distinctive Use of Theme

Thus far, we posit that Rebecca associates CT with a set of practices for conducting a lesson plan connected to her day-to-day work as a teacher candidate and a separate, largely disconnected set of skills around problem solving that seem closely related to her own experience participating in activities in the module she experienced as a student. Under this understanding, we might expect questions more aligned with the practice of conducting a lesson to lead Rebecca to draw on the former resources, and questions that ask about specific skills within CT to lead her to draw on the latter.

Later in our conversations with her, Rebecca is asked two questions: one that does not explicitly refer back to CT concepts she learned in the module, and one that does. In response to the question "Did you have students use tools to solve this at all? Like computational tools?" after clarifying that calculators qualify as a computational tool, Rebecca explains:

> *"Not the graphing kind, but also not the four function. There's like a middle ground between... [Scientific?] Yeah, okay, why use a scientific calculator only for the groups that decided to actually solve out for the slope formula, like y2 - y1? [What other tools did they use?] I don't... rulers? Does rulers count? [Yeah! Sure.]*
> *They used- because in order- when they were actually graphed it out, they wanted to make their lines. [Right, right.] They- some of them, they look at their notes, we allowed them to look at the notes if they wanted to look at their notes, but I don't think that's a tool. But their notes did have like steps to find the slope formula for those- for that- for those who were just being introduced to slopes. [Yeah.] What else? [Yeah] That's all I can think of... Yeah."*

Her focus in this response seems to align with what we have seen previously, leaning towards the theme *Doing CT as a Teacher* and the sub-theme *Computational Tools* (allowing students to use a calculator, particularly for groups that needed it to support their use of the slope formula, as well as rulers and notes to support other solving strategies).

In contrast, when asked "Did you see things in your list from the students in the class?" Rebecca draws on the resources associated with her list of terms or skills from the list. She notes,

> *"A couple of them mentioned sol- problem solving. A couple mentioned well within like computational tool is like breaking down like the problems, which is I believe is a part of it, or taking smaller steps to solve what the problem at hand."*

In this short response, we nonetheless see repetition of two of the ideas Rebecca previously expressed about CT skills: "problem solving" and "smaller steps," drawn from her list of ideas that came from her earlier experience in the module. When this list of ideas is directly invoked, Rebecca looks for references to them in her students' work.

In the second interview, after Rebecca has had the chance to consider the prompt of which lesson to infuse with a CT activity, she returns with a decision and talks through her planned implementation of the lesson. She has decided that the best choice is a lesson on systems of equations. The question "And why did you decide to go with that?" leads to the following response:

> *"So in terms of just having- so a lot of wi-with my students, I feel like they thrive better when they have a really good base of a content. Even if it's more traditional setting, they really like it to be honest, they like sitting down and they're like taking notes. And they don't- they don't really... they don't really like those type of assignments where like, oh, figure out your own, what is this? They like, are like, kind of like, are like, puzzled by it? Because they don't... I don't know. I don't know. So anyways, with that thinking in mind, I think it would have- would have just been better just to do a more challenging activity with systems, because they have been working on it slowly to a point where they can try to make those connections. Versus if I- if I just jumped in with something new, they would they'd really just be put off by it."*

While we know that Rebecca has a list of CT skills that she has previously linked to student activity she's seen in other lessons under the right questioning, we do not see her default to bringing up those terms here. This is likely a product of the question focusing on the appropriateness of this lesson for a CT infusion, which leads to a response based on this lesson's position in the unit, the assignments it contains, and the level of challenge it offers – more aligned with the *Doing CT as a Teacher* and *Class Suitability* themes. Perhaps because the list of ideas from the module is not directly invoked here, she does not bring up ideas related to *Doing CT as a Learner*.

Eileen

While Eileen's interviews shared many codes with the list we generated from Rebecca's interviews, they were mostly organized in a dramatically different fashion. Eileen tends to talk about CT elements both as connected to her experience from class and potentially connected to uses in the classroom. Across several different concepts in CT, she uses class resources from the course module and generates ideas about how to use CT in classroom practice. With a heavy focus on the concept of algorithms, Eileen fluidly uses knowledge from academic frameworks about CT and her group's brainstormed ideas about CT to spark ideas about math teaching.

This way of talking about CT generally did not fit well with the division *Doing CT as a Teacher/Doing CT as a Learner* as Eileen tended to discuss these in conjunction, and tied learning experiences from the course module straight through to plans for class activities. Therefore, we largely organized these codes into themes by topic to present them here. Predominantly, Eileen's codes fall into the theme *Process*, which broadly consists of moments when Eileen conceptualizes CT as focusing on the process of solving a problem rather than the solution itself, defining step-by-step processes, and generalized processes to solve multiple kinds of problems. Some of her remarks were themed as *Abstraction & Decomposition*, which spanned comments about decomposing problems as well as "decoding" important information from problems. We did find a handful of times where Eileen divided CT into *Teacher/Learner* experiences, and grouped these under the same themes we saw from Rebecca. Finally, one passage from Eileen's final interview did not fit well with any of the above themes, as she spanned multiple topics while talking about how she saw CT as a whole; this, we themed as *Everyday & Unexamined* to capture her thoughts about CT being done frequently, but not thought about explicitly.

Doing CT as a Teacher

Eileen had several remarks that we coded and themed under *Doing CT as a Teacher*. These were moments where Eileen was conceptualizing CT in a way relevant to practical classroom teaching decisions. As with Rebecca's codes under this theme, these relate to concepts that Eileen does not link back to the course module. The sub-themes are presented in **Table 2** below.

Table 2. The sub-themes observed in *Doing CT as a Teacher*, with a representative segment from Eileen's transcripts as an example of each.

Sub-Theme	**Example**
Culminating Activity/ Higher Level	Peter "So I guess, I guess my question is, do you expect to see anything that you'd think of as CT-ish from the activity so far?" Eileen 6:26 "I'm not entirely sure. Maybe like the wrap up, like the reflection part of it is more-so asking them to look back. Like, what did you do? What was the process of that? And how did that, you know,

	lead to your results, like whether the equations were equivalent or not?”
Student Choice/ ”Figure It Out”	“Like, for example, like multiplying, they could either use, like, the area model, or they could just do it like, standard algorithm. And it's fascinating to see the process play out, kind of side by side.”

In these segments, Eileen expresses priorities for the lesson that are not linked to expected learning goals of our course module, but do seem closely related to routine decisions for lesson-planning that a teacher frequently has to make. This is similar to the usage of this theme in Rebecca’s transcripts.

In the realm of *Student Choice*, Eileen seems to continually place value on leaving at least some prompts open-ended with multiple possible answers. For example, when constructing a task on equivalent expressions, she says: “Like if I give them like, okay, it's 5e, how would you write an equivalent expression for that? Or if I give them like 6x + 3? How would that look?” There is not one correct answer here; in fact, Eileen later says “I’m going to put this in here, so that they don’t get confused with me like Can I do this? Can I do that?” and writes “There’s more than one possible solution for each prompt” on the slide as an extra instruction. She notes, “Because like this one [2x + 3], you could leave it, you could write this as x + x + 3, or you could do 2x + 2 + 1.” This seems important to a CT-integrated lesson to her, a feature we also noticed as Rebecca was planning her lesson. However, there was not anything explicitly included in the CT course module that discussed leaving tasks open-ended or making sure there are multiple possible answers. One possible explanation is that including CT in teacher education encourages teacher candidates to think about more student-centered math teaching, as posited by work from Walton & Walkoe (2021), which notes that CT instruction may bring with it a tendency for teacher candidates to use more practices associated with ambitious math instruction and a focus on student understanding.

Doing CT as a Learner

Eileen makes several comments whose codes fall neatly under the existing theme *Doing CT as a Learner*. These codes, summarized in **Table 3** below, span several concepts drawn from experiences in the course module, largely the CT activities that teacher candidates participated in in Lesson 1.

Table 3. The sub-themes observed in *Doing CT as a Learner*, with a representative segment from Eileen's transcript as an example of each.

Sub-Theme	**Example**
Programming	Peter "Oh, yeah. So what about the robot?" [Eileen had previously mentioned a robot, probably the Sphero robot from Lesson 1.] Eileen "We drove it around? Yeah, it was something there was something about, like, the data and how we put it in or something to make it move a certain way."
Computational Tools	"We did an activity where we looked at how the kids were doing some kind of area model by walking around on like, the like, using a meter stick. And measuring like, some kind of distance of like a tiles to figure out how big or something the box was."
Trial & Error/Experimentation	"The bug thing, like, collecting data was part of it. Manipulating- it wasn't manipulating it, they kind of

	manipulated- because, you know, we, like, messed around with like, the data.”

Each of these segments seems to refer to one of the early activities that candidates participated in during the module – a Sphero robot programming task from the Sphero.Math curriculum (Weintrop et al., 2022), watching a video where two young students programmed a Sphero robot to navigate through a maze, and “Purple Bugs,” an online simulation where bugs and grass grow in a controlled environment where properties of each entity can be manipulated to see how it affects the ecosystem (Weintrop et al., 2014).

These codes were placed under the *Doing CT as a Learner* theme because, as Rebecca used knowledge themed under the same name, Eileen generally does not bring these experiences directly to bear when planning instruction. Instead, they seem sealed off and separated as experiences exclusive to the learning experiences she had in the course module. For Eileen, this separation is less common than it is for Rebecca; as we will see below, she often connects ideas from the learning module directly to her teaching practice.

Process

The most prominent concept that Eileen seemed to associate with CT were “processes,” which she also sometimes referred to as “algorithms.” Throughout discussion of this concept, Eileen consistently made efforts to translate her experience in the course module to similar ways that these processes could be productively used in the classroom. In other words, *Process* unified experiences from Eileen’s experience learning about CT to her plans to teach CT, rather than dividing down a *Teacher/Learner* split as seen in some previous concepts. Much of this discussion was prompted by her review of her group's brainstormed slide to describe and define CT, particularly the blue virtual post-it note shown here in **Figure 1**.

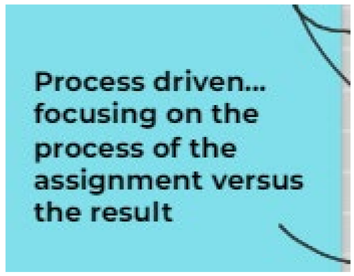

Figure 1. One of Eileen's group's notes on process as part of CT based on their experience in class.

She discussed the content of this note and then quickly shifted to using a similar concept in class, emphasizing knowledge of different processes in search of a solution:

> *"I like the one where it said like, was more about the process or than about like the result? Because like in math, like obviously, there's like a bajillion different ways you could solve something, right? So like, having- having different process available to the student, I feel like is a good thing to have and like, helps with differentiation."*

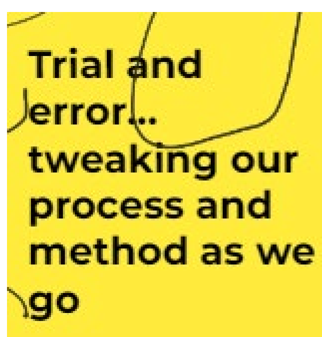

Figure 2. Eileen's group's note on trial and error as part of CT, again based on their experience from class.

Eileen continues to fine-tune her conceptualization of process and result as she discusses the “trial and error” her group had mentioned, seen in the yellow post-it note shown here in **Figure 2**:

> *“I mean, tweaking as we go, I feel like kind of makes sense. Because even for a program, like when you're coding a program, if it's- if it doesn't work, then you're gonna find where the error is and fix the error. Right?... So like, for example, again, with like, solving the equation, like if they're going through it, and their final answer, when they check in, it's not correct. So they have to go back into their work to see okay, so where did it go wrong? What do I need to change? kind of idea?”*

Here, Eileen starts by discussing debugging while coding. She may jump straight to debugging because one of the course module experiential activities was a Sphero robot coding activity in which she and her fellow classmates had to modify and debug a program that rolled the robot one meter to transform it into a looping code that would measure the length of the classroom. She then translates this experience to reviewing work to check for mistakes on a math problem, using the result to evaluate the process in the context of a math classroom. In both cases, she discusses the end result as an indicator to evaluate the process and see if it’s working correctly. A correct or incorrect result serves to indicate that the process is or is not working. An important takeaway from this discussion is that Eileen conceptualizes CT as emphasizing process over answer, with the answer mostly only serving as an indicator of whether or not the process is functioning correctly.

Eileen’s discussion around *Process* centered around a large number of sub-themes, described in **Table 4**. In each of these sub-themes, other ideas interact with the core idea of a process.

Table 4. The sub-themes observed in *Process*, with a representative segment from Eileen’s transcripts as an example of each.

Sub-Theme	Example
Trial & Error/Result as indicator of a correct/incorrect process	“With solving the equation, like if they're going through it, and their final answer, when they check in, it's not correct. So they have to go back into their work to see okay, so where did it go wrong?”
Connecting process ↔ concept	“CT could play in, in the sense of like, okay, so one student brought up, hey, [in multiplication] the two is being added over and over again, it's like we're skip counting. So if we're skip counting, that means we are multiplying.“
Applying a process	“Is this like a process of like, given a problem, they apply a formula?”
Conditional steps	“Because that's kind of what we've been doing with the different like, topics and units that we're in, we would go through- I would kind of write down- we write observations and rules. So basically, if you see this, what do you do? Like last unit we're working on dividing fractions, so if you see a fraction in your divisor, what do you do to it? So first, fraction, if you see a fraction only in your divisor- if only that happens, then you apply the rule is basically what we did. And we wrote, we actually wrote down the rule, and then we see the problem, but that's okay. So if I see this here, what I do, do I apply the rule, or do I not apply? So that's kind of like that computational thinking there, where it's like, okay, if it's a yes, and this happens, if it's a no, then you know, you move on.”
Changing the direction of an ordered process	“Well, I guess, when they did it going forward, they had five come first. But if now that’s the finish line, and they're working backwards, like they just have to start with what they got last, that kind of like, build backwards. So thinking backwards?”

Generalizable solutions	"And then we'll do the whole reflection. And then I guess, actually going over it, and then writing down the process that they can apply to any problems."

Eileen continues to refine her conceptualization of algorithms as she considers what activity to integrate CT into in her coming lessons. Currently, as her class is working on writing and solving equations, she saw this process as a sort of algorithm:

> *"Maybe in the sense of like, solving any equations. So I'm- in my other math six class- my on-grade-level one, we are working with tape diagrams. So I give them the tape diagram, from the picture, they need to write an equation. So they have to like, write down what it means, like if they see three x's, how would they write that? Balance it and then from there, the next step would be to rewrite the equation to an equivalent equation before they can solve it, because we're learning this step by step. So they haven't like, you know, done at the algebraically, the algebraic way where we just do it, you know, solving downwards, but we're kind of going step through like, Okay, you see the picture, represent that picture as an equation, or the word problem as an equation. And then you rewrite the equation so that x are your variables on one side, and then you have everything else on the other side. So if you have like, x plus three is seven, when you rewrite it has to be x is equal to seven minus three. So in that order, and then they solve for x. And then they check it."*

Eileen generally seems to conceptualize *Process* as a strict series of specific steps that need to be followed carefully, similarly to how a computer scientist might think of an algorithm. Her chosen task for integrating CT in her class follows up on this:

> *"I feel like maybe present them with a problem, like, like a word problem, or like an actual problem, like a math problem, and then have them write out the steps that they used, and then maybe tell them to pass it to another neighbor? And then give them a different problem. So they can solve it using the same steps?"*

This modification of an equation-solving task emphasizes students going beyond simply using a process and instead explicitly defining it. Students are not only being asked to use a process to solve a problem, but ideally define that process in a way that is somewhat generalizable to other problems. Sometimes it is difficult to parse out exactly where mathematical or algebraic thinking differs from computational thinking, as both involve algorithms in some capacity. One way to define that difference is this: mathematical thinking often involves using algorithms, such as methods to solve an equation, but rarely (at least in K-12) involves defining them. As an example, we would think of writing a general algorithm for solving an equation as a CT-enhanced version of a mathematical learning activity, because defining these steps generally is not a routine activity in a math classroom. This is also an example of where a CT integration may encourage greater student understanding of the mathematical content involved. Eileen's plan for this activity seems to more clearly cross that line into CT-enhanced territory: algorithms are not just something to be used here, or a pattern to be followed, but instead a process to be clearly defined by the students in a way that goes beyond what the average math classroom might include. This is a strong example of how CT can enhance learning in a mathematics classroom by encouraging students to dig deeper into understanding the processes they use in class.

Other sub-themes under *Process* suggest that Eileen has a robust and thorough understanding of this concept with a number of flexible connections to related CT and programming concepts. For example, *Conditional Steps* adds the idea that some steps in a process might not always be followed depending on the circumstances of the task at hand. Eileen even alludes to "if-then" language, with apparent connections to formal logic or programming. When she watches a video on students reversing a Sphero program to make a robot go backwards through a maze, she notes that reversing the entire process will mean "they just have to start with what they got last," suggesting an understanding that to reverse a process, you need to reverse the order of that process.

Eileen's final planned activity is modified slightly based on her class's progression through the unit. In a lesson on equivalent expressions, she includes the following activity:

EXTENSION TO PRACTICE:

Given…

- If you had *y+y+y+y*, you can write it as _______.
  - We know this because ________________.
- If you had *6c*, you can write with addition such as: ______________________.
  - What if you had 6c + 3? __________________
  - What is your process to write equivalent expressions?

Figure 3. Eileen's modified activity emphasizing the process of writing equivalent expressions.

The final task here asks students to define a process for writing equivalent expressions (as an example, Eileen described a student taking "6c + 3" and writing "4c + 2c + 2 + 1"). Eileen's goal with this was to have students "write a process that they could apply to any problems." Her conceptualization of algorithms, then, seems to be that they are generalized processes to use in multiple similar contexts.

Abstraction and Decomposition

Eileen also mentions "decoding," a concept that seems to sit near what CT researchers would likely call "abstraction" and "decomposition." She describes:

> *"Because, like, again, on the poster, one of the things that stood out to me was like decoding, like decoding a problem? Yeah. So like, I would say, maybe a tool that we practice in the classroom at least is how to read the problem. And like, what to underline in the box, like, what I've been getting them to practice doing also, because my class is a heavy EMR kind of class. So dissecting a word problem, really breaking it down is kind of challenging sometimes. So we've really been practicing, like, underlining information that's important. And then boxing our question."*

Because she focuses on algorithms as the topic she wants to include in her lesson, Eileen does not revisit this topic. However, this small passage is significant because it follows the same pattern seen as she discusses algorithms: Eileen refers back to a concept discussed when she was learning about CT and then applies it to a way it can be seen or used in the classroom. What is particularly interesting about this comment is that there is no "decoding" explicitly mentioned in any of the CT resources we reviewed with Eileen, or those used to introduce the subject in class. Here, she seems to be already translating some CT ideas about breaking problems down and abstracting out key information into the classroom practice of decoding problems.

Everyday and Unexamined

In her review of the lesson and how it went, Eileen also summarizes how she feels about CT's role in the classroom and everyday life, crossing from algorithms to decomposition:

> *"Because I feel like [CT]'s in what we do every day. But we just don't like, think about it. And like it's kind of maybe one of those things where we kind of take for granted like, Oh, we're just like moving in blah, blah, blah, going flow. But like if we focus on a bit more, it might help. Like, I feel like because math is very process driven. Solving equations like you have to do it a particular way, combining terms you do in a particular way, like finding anything in math is like, word problem, what are you gonna do, break it down? How do you break it down? Math is very process driven, in my opinion. So I think it brings an interesting approach to how to present the information to students. And like, you know, I think it can be helpful. Yeah."*

Here, Eileen lays out a view that CT concepts – like algorithms – are consistently used, but perhaps not as consistently examined in depth. She describes defining a process as a useful teaching technique because it presents the information to students in a different way while also having them focus on something they frequently use, but rarely *define* or *describe*.

Discussion

This study reviewed a teacher candidate and a teacher's conceptions of CT as seen in a multi-part interview to plan a CT-integrated lesson in each of their math classrooms. This interview occurred a few months after the teacher intern, Rebecca, had completed a module on CT in her math & science methods course in Fall 2021 and approximately 1.5 years after the teacher, Eileen, had completed a modified version of the same module in Fall 2022. Inductive codes were used to describe segments of each teacher's responses from the transcript, followed by organizing these codes into themes. In our analysis, we found the themes *Class Suitability*, *Doing CT as a Teacher*, and *Doing CT as a Learner* helpful for structuring Rebecca's coded responses; we found it more productive to use the themes *Process*, *Abstraction & Decomposition*, and *Everyday & Unexamined* to group Eileen's responses because of key differences in the way she used her knowledge about CT through the interviews.

When considering the implications of these findings for teacher educators, we find that the CT module appeared to be beneficial for both teachers. While the teachers use CT in somewhat different ways, we note that they have each learned something about CT activities that is used to enhance the lesson they plan. For Rebecca, learning about CT includes characteristics of how a CT lesson is enacted that include high-leverage math teaching practices such as having students defend their mathematical ideas in a group setting. Eileen's learning about CT appears to focus more on how to apply particular CT concepts she remembered from specific activities she did during the module to students' mathematical understanding. Each of these enhances the lessons the teachers plan in different ways.

Rebecca's conception of CT includes more and different elements than what was taught and discussed in the module. The theme *Doing CT as a Learner* captures Rebecca's connections back to activities she completed during the module and the skills and practices needed to complete those tasks. However, we also saw the theme *Doing CT as a Teacher*, which consists of segments where Rebecca talks about necessary features, designs, and requirements of activities and tasks to integrate CT in the classroom. While there is limited overlap on a few concepts between this and *Doing CT as a Learner*, most of this theme does not seem directly related to CT concepts discussed in the module. Sub-themes such as *Group Work* and *Culminating Activity* are particularly notable because the module does not explicitly set up CT as something that must be done in groups, or must be a capstone activity on previous learning; however, Rebecca consistently refers to these as seemingly required features of a CT-integrated lesson. One potential explanation is that Rebecca's learning included features of the module lessons themselves more than the CT concepts within them. The CT module activities – often done in groups, and often drawing on math & science concepts with which our undergraduate teacher candidates were already familiar with – may have instilled these as necessary features of CT lessons. The *Class Suitability* theme is also noteworthy because we cannot see any way that its ideas – organized into the sub-themes *Student Characteristics* and *Class Logistics*, each referring to a practical element of teaching a particular class with distinct students and class periods – can be tied back to the CT concepts we intended to include in the module. Instead, this theme consists of considerations she has likely gleaned from the practice of teaching as a full-time intern. These daily considerations about what activities will work well with which classes are likely so routine for Rebecca that they accompany her other knowledge about CT almost instinctually. Together, Rebecca's CT learning and day-to-day teacher practices produced a lesson that included ambitious math teaching practices and many organizational features that could be traced back to similar lesson features from her CT learning experience.

Eileen focuses heavily on material that aligns with the CT content discussed in the module, as Algorithms, Abstraction, and Decomposition were each topics of focus included within the PRADA framework (Dong et al., 2019). Her thoughts about CT often flow seamlessly from her experience in the course module and descriptions of different CT concepts into potential applications of these ideas in the classroom. The lesson she planned encourages students to think about the process by which two expressions are found to be equal (combining variable terms and constant terms, then checking to see if coefficients match across the two expressions) and how this process can be generalized to write many expressions equivalent to a certain expression. Eileen also commented that CT underlies much of the problem-solving we do, but that we do not always consider how we are using it. This mindset seems to set up a metacognitive lens for students to more closely examine how they are using CT concepts to help break problems down, identify their key elements, and solve those problems.

For mathematics teacher educators, these outcomes both seem positive. Despite differences in the exact features of resulting lessons, both teachers incorporate elements that are desirable and focused on students' deep understanding of a mathematical topic when asked to include CT. This suggests that learning about CT and being asked to use it in lesson planning helps math teachers plan better lessons for student understanding. CT integration can be viewed as supporting math teaching reforms by focusing teachers on student understanding in one way or another.

We also recognize that designers of CT learning experiences for teachers might be interested in the differences in what knowledge our two teachers associated with CT. Rebecca tended to remember more organizational features of a lesson, while Eileen referred more to concepts included in the module materials. This difference is significant particularly because of the differences in lag time of the interviews for both teachers. Eileen was interviewed much later relative to completion of the course module (15 months) than Rebecca was (5 months). Our expectation was that Eileen would use less of the specific knowledge elements introduced in the module, and more of knowledge she had acquired more recently, such as on-the-job as a teacher. We expected this particularly because at the time of the interview, Eileen had been a full-time teacher for almost 6 months with her internships beforehand, whereas Rebecca was only 3 months into her full-time internship. However, what we seemed to find was that Eileen, more than Rebecca, used knowledge apparently acquired from the course module actively to think of applications to her classroom and in the lesson-planning task.

We have two potential explanations for why this difference in knowledge use is opposite of what one might expect. The first is a framing argument: the two interviewees may simply have been making sense of the task in different ways, and drawing on a different set of resources as a result (Hammer et al., 2005). Eileen apparently understood her task as remembering CT knowledge elements specifically for use in the classroom, as her consistent attempts to translate from her own experience to potential student experience indicates. Rebecca, on the other hand, may have understood her task as remembering CT knowledge learned from the module, and separately constructing a lesson integrating CT. The difference may explain why Rebecca produced a recollection of elements and activities from the module that she didn't use in the lesson-planning task.

Another potential factor is that the course module was revised between the Fall 2021 and Fall 2022 iterations. The revisions focused on making the module "Experience First, Formalize Later" (Stats Medic, 2018), which emphasized having candidates participate in CT activities and brainstorm a list of terms to describe and define CT before being exposed to formal academic frameworks on the subject. This revised emphasis on having participants describe the key elements of the activities in their own words may have made these terms more readily accessible and familiar; earlier iterations that included earlier looks at the frameworks may have set CT up to be a list of somewhat unfamiliar terms to be memorized. The earlier approach seems to lend itself more readily towards storing CT as inert knowledge, rather than knowledge ready to be actively used.

In addition, the revisions to the module increased the time spent on the CT-integrated lesson planning activity. The earlier approach asked candidates to create a CT-integrated lesson plan in their subject area, then come in and discuss how a few other integrated lesson plans worked, and revise their plan based on that experience. The new approach focused more on the individual candidates' lesson plans; when they brought in their lesson plans, they were partnered with another teacher candidate, presented their lesson plan to them, and received individual peer feedback from that teacher candidate, as well as some big-picture suggestions from the instructor. This may have focused participants more deeply on their personal lesson plan, rather than spreading their attention over several integrations. Focusing deeply on one lesson plan (and, in most cases, one or two CT concepts) could also encourage a smaller total number of CT knowledge elements that feel "familiar" but a greater familiarity with each. In other words, while teachers may not walk away from the module with as great a breadth of knowledge about CT, they may walk away with a greater depth of knowledge in a few concepts and how to apply them in a lesson-planning context. In a perfect (and likely unattainable) world, candidates would walk away from this module with a wide breadth of knowledge about CT and a deep understanding of how to apply it in their discipline's classrooms. However, the increasingly large number of competing demands on teacher candidates makes this largely unfeasible, at least with the current arrangement of most teacher education programs. The theory of preparation for future learning (Bransford & Schwartz, 1999) suggests that this may not actually be a problem: one of the core assumptions of PFL is that learners rarely walk away with a complete understanding of the field they have learned about, and in many cases in fact retain very little knowledge from a short, initial foray into a subject as this CT module represents. The PFL perspective suggests that it is better to be prepared to incorporate future learning into an existing knowledge framework, especially in careers like teaching where we do not expect learners to be done with their learning when they begin teaching. The existence of a small amount of persistent knowledge, with limited scope but great staying power, might set teachers up for more success with CT in the long run. One could imagine a teacher using their experience with integrating one CT concept into a lesson plan and broadening that to learning new concepts and integrating those more easily, perhaps, than a teacher with a long list of CT concepts who is less familiar with how to use them. This would suggest that better designs for CT learning experiences for teachers and teacher candidates might include introducing CT through experience with specific activities, focusing on a palatable handful of CT topics, and assigning applied practice integrating these specific topics into STEM lessons.

Conclusion

In this work, we reviewed how two teachers discuss their knowledge of CT and their use of CT in their math classrooms following an instructional module on CT embedded within their STEM methods course. We found that both teachers enhanced their math lessons with beneficial teaching practices when asked to include CT, suggesting general benefits to including CT in teacher education. We also found that the teacher who had been through the experience-first version of this module tended to connect her practice more directly to concepts deliberately included in the module, especially with the particular domain of Algorithms. This suggests that introducing CT via experiential activities and focusing on application of select domains within CT to STEM lesson plans might prepare teachers better to translate their learning experiences into effective CT-integrated STEM lessons. The PFL perspective (Bransford & Schwartz, 1999) encourages viewing the learning outcomes of this CT module as initial steps to effectively using CT in the STEM classroom, not as the last learning on the subject we expect teachers to do.

Future Directions

This paper suggests several productive next steps for research on integrating CT in STEM teacher education. First, our two case studies indicate that an experience-first introduction to CT may prepare teachers to translate their learning smoothly into classroom practice. Additional data collected from a larger sample of teachers – particularly in a variety of program contexts – could help confirm this pattern. Second, our work emphasizes the importance of collecting in-depth qualitative data from teachers in this work. Both teachers we worked with initially indicated that they did not remember much, or anything, about CT, and we expect that a quantitative self-report measure of their feelings of preparation to use knowledge about CT in the classroom would have indicated poor outcomes for their learning. The data discussed here, however, tells a different story – their actual use of this knowledge far exceeds what they believe they can do with it. Other researchers should remember this when evaluating outcomes for their own programs. Third, more longitudinal work is necessary in this field when considering how STEM teachers are prepared to use CT in the classroom. The PFL perspective suggests that these learning experiences should serve as initial preparation for using CT in the classroom, but that their full preparation might include many more learning experiences throughout their career. As the use of CT in K-12 education continues to expand, looking at this long-arc perspective should be a focus for understanding how teachers are using their knowledge about CT and how that knowledge continually evolves over time.

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Chapter 4: A Faculty Workshop on CT Implementation within Mathematics and Science Methods Courses

Introduction

A known issue in CS education, and STEM education more broadly, is inequitable access to learning opportunities, particularly for historically underserved groups of students (Leonard et al., 2021). STEM teacher education that includes CT begins to resolve this issue by providing every teacher with the knowledge and skills to integrate CT into their classrooms, and thus provide opportunities to learn about CT on to all students. However, the impact of this work will be limited until it can be integrated into teacher education on a broader scale, as integrating it within one program only passes on the knowledge to teachers from that program. A more sustainable approach would be a statewide implementation that embeds CT within every math & science teacher education program, as this would ensure an equitable roll-out of knowledge throughout all classrooms in the state.

Our goal with our modular integration has always been to provide resources for other faculty throughout the state and beyond to integrate instruction on CT within their own STEM teacher education courses. Towards this end, we held a half-day virtual workshop with instructors of math & science teaching courses (or those closely related) in June 2023. In this workshop, we discussed CT concepts and frameworks with participating instructors, reviewed our own experience integrating

CT in a math & science methods course, and gave time for instructors to discuss and develop their plans for CT integrations in their own methods courses. After the workshop, several instructors participated in follow-up interviews to discuss their CT-integrated methods courses as they began teaching them that fall semester.

This paper will discuss the theory and strategies that went into the development of this workshop, as well as findings on instructors' initial conceptions of CT, how they discussed it in interaction with one another, and what implementation profiles looked like in instructors' methods courses. This work contributes both to an understanding of how faculty instructors of STEM methods courses view CT and how it relates to their own work, and a set of case studies on what CT integration looks like in these courses and how instructors use resources about CT to modify their courses in this way.

Literature Review

CT and Teacher Education

To create equitable educational opportunities on a broad scale, teacher education programs must pass on the desired knowledge to every teacher to prepare them to teach every student. In a review of current professional development (PD) on CT, Espinal and colleagues (2024) noted that it was crucial to include CT in teacher preparation efforts because there is currently "no clear approach to integrate computational thinking across primary and secondary school curricula," (p. 12). It is insufficient, for example, to have faculty at one university including information on

CT in one methods course, while other universities do not include it in their coursework at all. However, this is the predominant strategy used in most current PD on CT (Yadav et al., 2011; Pollock et al., 2019; Ketelhut et al., 2020; Moon et al., 2023). While these approaches provide proof-of-concept for introducing CT integration to STEM teachers, they do not function effectively at scale because they rely on the presence of specialized experts.

It is also insufficient if University A and University B both pass knowledge on CT to their teacher candidates, but that knowledge is inconsistent. This may lead to teachers preparing students with different levels of mastery, or even differing views on what the subject or concepts within it even are. For the universities to prepare their teachers in a compatible manner, course developers and instructors at each university must share common ground about the knowledge they want to include. This is the main goal of the CT faculty workshop: to bring instructors together from universities across the state to discuss current strategies and practices with CT, voice disagreements with incompatible perspectives, and informally feel out what is an acceptable middle ground to build knowledge upon.

PD for faculty instructors has been shown to be quite effective, both at changing teaching practices and improving learning for those instructors' students (Rutz et al., 2012; McKee et al., 2013). However, in the same way that teachers do not always enact the same practices or values they espouse or report (Sam & Ernest, 1997), there are some indications that changes in university faculty instructors' practices also do not match what they say about changes in their practice (Ebert-May et al., 2011). These findings suggest that PD can be productive for faculty instructors, but that it needs to be done in a way that connects espoused and enacted practice in a way that cannot be avoided. The work by Ebert-May and colleagues also suggests that Likert survey items are an ineffective way of measuring progress because participants likely have a good sense of what the PD instructors are hoping to see, and there is no additional effort required to misrepresent changes in values or practice by responding more positively, whether purposefully, accidentally, or unknowingly. This suggests that deliverables, such as lesson plans and specific action items to pursue, might be better measures of the success of a PD.

PD for teacher educators is also an underutilized area. Teacher educators often do not have many opportunities for training, in-service PD, or reflection on their practice (MacPhail et al., 2019). When used, PD for teacher educators has positive results on cognition, behavior, self-esteem and enthusiasm for teacher education, particularly when there is time for teacher educators to reflect on their practice (Koster et al., 2008; Körkkö et al., 2016). Other research suggests that cooperative learning with peers can make for more effective PD for teacher educators (Boei et al., 2015). With our current workshop, we have ensured that instructors will have time for reflection on their own practice and how to integrate CT into their courses, as well as ample time to discuss these developing plans with peers.

Preparation for Future Learning (PFL)

A traditional view on teaching might suggest that at the completion of a course or training, learners should immediately be prepared to apply their acquired knowledge and skills to tasks that are the same or similar to those learned about in the course. But what should be done when learners will be asked, in the future, to perform tasks in the same domain as the original content but drawing on different learning resources? This is a key question when thinking about our workshop, which is intended to get participants thinking about ideas in the still-evolving field of CT. We do not expect that academic understanding of CT and its domains is complete as of 2024, and so instructors will need less of a specific understanding of current frameworks and practices, and more of a flexible readiness to handle different resources for CT in teacher education.

To consider how to prepare instructors for this form of readiness to use CT in teacher education, we turn to research on Preparation for Future Learning (PFL). Proponents of PFL argue that "optimal learning experiences can be quite different depending on the characteristics of the knowledge domain the students are likely to encounter in the future," (Spiro et al., 1987, as cited in Bransford & Schwartz, 1999, p. 78). In fact, when the kinds of problems that will be encountered in the future are unpredictable and may not closely resemble the kinds of problems that learners have seen before, it may be best to focus on conceptual understanding of problems over techniques like skill-mimicking and memorization. In their study of PFL's application to learning in health professions, Mylopoulos & colleagues (2016) write,

> "Guided discovery learning activities stimulate trainees to develop their understanding of a problem to be solved, in contrast to copying a told solution for a task they never experienced as a problem. Evidence from a number of studies suggests that guided discovery helps trainees to identify and activate their own knowledge, to clarify the different forms of knowledge they possess (e.g. conceptual versus procedural), to experience variability as they try different strategies for problem solving, and to formulate a better understanding of problem features." (p. 119)

Grappling with problems, then, might offer learners a more flexible end-product from their learning. Rather than learn how to solve a particular kind of problem, a focus on understanding may help learners identify key features of that problem, identify features that contrast with other kinds of problems, and most importantly learn how their own knowledge can be leveraged to solve different kinds of problems, as well as what additional knowledge they might need to acquire in order to solve these problems. "Rather than an evaluation of whether people can generate a finished product, the focus shifts to whether they are prepared to learn to solve new problems," (Bransford & Schwartz, 1999, p. 69). In our work, we focus on encouraging instructors to apply their knowledge of CT directly to course applications, thereby practicing the skill of how to integrate CT concepts into their methods courses. While their knowledge of CT may evolve as they learn more and additional research on CT is written, the core features of how to integrate CT concepts into methods courses will be established.

In cases where we are preparing learners not to perform a particular skill, it may be more important for them to possess adaptive expertise than routine expertise. "Routine expertise is useful for stable, recurrent tasks where there is a premium on efficient completion. Adaptive expertise is useful where there is a high degree of variability and change, and it is important to learn new ideas and ways of accomplishing outcomes," (Mylopoulos et al., p. 116). For some learners, it is absolutely necessary to be exceptional in a particular skill: we would want a neurosurgeon, for example, to be very, very skilled at the exact type of surgery they were going to perform, just as we would want an elevator safety inspector to be extremely good at the particular skill of inspecting elevators.

For our faculty instructors, on the other hand, it may be more important to walk away from this learning experience possessing a more adaptive expertise in CT, and how it applies to the classroom. There is, after all, no particular task they must perform with this knowledge, no test that measures their performance on CT integrations, and no one way to fit CT into their courses. In fact, because each instructor is teaching a different course in a different university context, their implementation will have to look different. We also expect that in the future, available information about CT implementations within teacher preparation programs will continue to develop and evolve. While adaptive expertise in CT might not be the most efficient solution for the short-term task of integrating CT into courses immediately after the workshop, it might be vastly more valuable to our faculty instructors in the long term, particularly as understanding of CT and how to integrate it into the classroom expands, along with new technology to do so. This makes PFL an important perspective to consider when considering the outcomes of this workshop.

A positive outcome from a PFL perspective might look different for different instructors. However, here are a few examples of what we might hope to see from workshop participants. First, we might see a teacher educator who modifies a small number of activities, or only one activity, throughout the course. Assuming this modification is productive for incorporating CT, this behavior would indicate that the instructor understands what CT integrations can look like and is prepared to continue doing this work as they learn about more relevant CT activities and new ideas for how they might apply to their course. Second, we might see a teacher educator who shares new resources they've found independently and how they have used them in their course. This would suggest that the teacher educator is prepared to incorporate new learning about CT into their practice.

Differential Effects of One-Off PD on "Ready-to-Learn" Participants

Prior research on professional development (PD) duration suggests that sustained timelines are more successful (Garet et al., 2001; Crowther et al., 2002). A review by Darling-Hammond and colleagues (2017) concludes "Though research has not yet identified a clear threshold for the duration of effective PD models, it does indicate that meaningful professional development cannot be accomplished in short-one-off workshops," (p. 15). We acknowledge this to be true for what we typically think of as "PD": experiences with specific learning goals in mind that aim to add or change a key element of instructional practice. However, our workshop does not have the same kind of learning goals: we do not expect instructors to walk away with a perfectly uniform idea of what CT is and how to use it in their courses. Instead, as noted in the PFL section above, we want instructors to walk away with an adaptive expertise in CT integration for methods courses and some ideas about how they might use it. Personalization is most apparent in our experience-first design: instead of stipulating recommendations for CT integrations and then demonstrating examples, we have instructors participate in CT activity experiences first and then develop their own thoughts about what CT is and how it could be integrated into their courses.

We also posit that our workshop might benefit from the principle of choice involved for the interested instructors who participated to offset the detriment of a reduced duration. This workshop is entirely optional and open to faculty if they want to participate. We have thus set up somewhat of a partnership, where only faculty instructors who wish to participate will participate (Knight, 2007). Despite no requirement to possess any knowledge of CT or to be using it in any capacity, we also assume that only instructors with at least some interest in CT will participate – this assumption was somewhat confirmed by every participant sharing at least some knowledge of CT in our introductions. Instead of your average professional development session – generally with a somewhat unwilling audience with a variable knowledge base – we have the opportunity to work with a quite willing pool of participants with at least some existing knowledge of the content we're discussing. We think of these participants as "ready-to-learn," as they have demonstrated the knowledge and motivation to adapt their practice already based on their participation. This "ready-to-learn" idea aligns with Guskey's (2002) Model for Teacher Change, which suggests that instructors' attitudes must be at least somewhat in favor of the practices covered in PD for the program to be effective.

An additional benefit of this "ready-to-learn" group is that, because of their existing knowledge on the subject, these faculty instructors are likely to enter our workshop with some expectations about what they want to learn. If the experience does not live up to their expectations, they are incentivized to tell us that and share negative feedback with us. In contrast to the national-level or large-scale PDs brought up earlier, faculty instructors in our workshop have less incentive to respond positively and more incentive to respond honestly if they are disappointed.

Goals of the Study

In this study, we examine the effectiveness of a summer workshop on CT for faculty instructors. We look both at the conceptualizations these instructors express during the workshop, as well as how the workshop appears to guide their plans for implementations within their courses. Additionally, we consider how the workshop may prepare them for future learning on CT integration and future course development. Our research questions guiding this investigation are:

1. *How do instructors conceptualize computational thinking in the context of a summer workshop?*
2. *How do instructors approach integrating computational thinking into teaching methods coursework after a summer workshop?*

Methods

Summer Workshop on CT Integration in STEM Methods Courses

We led a three-hour workshop on Zoom for interested faculty and other instructors of math & science teaching methods courses or similar courses (e.g., elementary methods course instructor). In this workshop, participants interacted with a CT activity simulating a wolf, sheep, and grass ecosystem (Wilensky, 1997) before discussing their current understandings of CT. We then discussed two frameworks of CT – the PRADA framework (Dong et al., 2019) and the CT in Math & Science Taxonomy (Weintrop et al., 2016). We concluded by presenting our current integration of CT within UMD's TLPL 423 before giving instructors some structured time in breakout rooms to plan out their own CT integrations.

Participants

10 faculty instructors (1 man, 9 women) from universities across Maryland attended our Zoom workshop. Three were instructors of elementary science methods courses; two were instructors of secondary math methods courses; one was an elementary math methods instructor; two were instructors of CS in education courses, and two were instructors of education technology courses. Instructors had varying degrees of self-described experience with CT: one said "I'm not convinced I even know what computational thinking is," and another described herself as "early in this

process” while others were actively involved with research grant projects to integrate CT into teacher education in different ways.

Understanding Instructor Conceptualizations

To understand faculty conceptualizations of CT as they participated in the workshop, we reviewed the video recording of the workshop as well as the accompanying transcript. Like in Paper 2, we approached faculty comments with an inductive coding approach without laying *a priori* assumptions about the content and organization of knowledge about CT on the data; instead, we tried to organize comments thematically.

Understanding Instructor Implementations

To understand instructors’ plans to integrate CT into their courses, we met with them for a one-hour interview on their plans for the course, including what activities they planned to include, whether there is a unit solely devoted to CT, and how many hours they estimate have been devoted to CT instruction. We also asked how their conceptualizations have been affected by participation in the summer workshop, or whether they have changed after that experience.

We looked for several criteria to determine whether CT was a primary course objective. First, considering our own module as a guideline, we ask if there is a unit or 3-5 lessons devoted to CT instruction. Second, we ask if many activities have been modified to incorporate CT, and if so, about how many; if 10 or more activities have been modified, we consider this sufficient to equally establish CT as a primary course objective. Finally, we ask the instructor to estimate how many hours in the course are devoted to CT instruction; assuming 45 hours of instruction across the semester, we called 9 hours and up (being 20% of the course content) enough to consider CT a primary course objective.

Data was collected from instructors at four time points. First, we video recorded the workshop itself to analyze the learning that occurred. Second, instructors who chose to continue with the study will participate in clinical interviews (see **Appendix B** for a list of questions) in the summer and fall after the workshop to better understand the impact of the workshop on their plans for fall courses. Third, the instructors that participated in the workshop and interview received a survey (see **Appendix C**) at the beginning of the semester with questions both about CT and, more specifically, open-ended questions on how they planned to embed CT into their fall and other future courses. Fourth, participating instructors will receive a similar survey at the end of the semester, primarily asking them to evaluate how they felt the CT-embedded course had gone, and any thoughts they had about how to modify their implementation in the future.

Findings

Faculty Conceptions of CT

After introductions and participating in a CT-integrated activity on population growth of wolves, grass, and sheep (Wilensky, 1997), we asked instructors to brainstorm ideas about CT based on this experience and past experiences. We found three main conceptualizations of CT through the following conversation. One instructor did not participate enough in our discussions throughout the workshop for us to categorize her thoughts on CT.

The first conceptualization of CT was that it was a collection of “things we do naturally when we approach a problem” that applies to many subjects and generalizes to solving many kinds of problems. This conceptualization thinks of CT as a relabeling of many common problem-solving techniques that learners do without having to be explicitly taught. One example is the process of baking a cake, which requires the baker to follow a specific set of instructions in a particular order; this view of CT would hold that “algorithm” is a way to describe the careful definition of this step-by-step process, and following it exactly, that the baker would have done anyway. Instructors who expressed this conceptualization tended to describe CT as something learners are doing already, or something coming naturally from past experiences. One instructor said that CT was “something we’re probably already doing in methods courses,” and said that her main interest was in learning to accurately name and describe these practices. This viewpoint seems to hold that CT is simply a lens through which to view problem-solving techniques and skills that learners might do anyway, and that this is a new way to organize and describe those practices. Three instructors expressed this conceptualization, including “Lucy,” an elementary science methods instructor whose interview we will discuss in the next section, a secondary math methods instructor and an educational technology instructor.

The second conceptualization several instructors expressed was that CT was a distinct set of technical skills from general problem-solving skills. One instructor noted that she felt there was a distinction between a "step-by-step process" and a "precise algorithm," with an "actual algorithm" fitting into what she thought of as CT, but a simple "list of steps" falling short. Another instructor distinguished "general problem decomposition" from her experience as a research assistant working with coding and computers, where problem decomposition was a "very different beast." Another instructor described "doing hypothesize-test-reflect methodically – less guess-and-check, more strategic changes." While these instructors acknowledged that CT practices often look similar to general problem-solving practices, their comments suggest that there is an additional technical and/or metacognitive level that distinguishes CT practices and skills. Five instructors (a secondary math methods instructor, two CS in education instructors, an elementary math methods instructor, and "Steph," an elementary science methods instructor whose interview we will discuss in the next section) expressed this conceptualization.

A third conceptualization viewed CT as a means of "enculturating people into computer science ways of thinking, vocabulary, and cultural norms." The instructor who introduced this idea referenced the Vygotskian concept of "cultural tools," (Vygotsky, 1978) suggesting that CT is a context that prepares students to communicate and learn in a new way. This viewpoint suggests that CT is somewhat of a stepping stone on the way to computer science. This conceptualization was uniquely expressed by one instructor, an elementary science methods instructor.

Spectrum of Strictness with Respect to CT

In reviewing faculty commentary from the summer workshop, we noticed a spectrum of "strictness" with regards to ideas about what qualifies as CT. Faculty ranged from "accepting" of almost all activities connected to CT, to "discerning," or only considering certain activities to truly qualify as CT. Discussion around an article that claimed "even making a cake is computational thinking" helped illustrate this spectrum best; faculty towards the accepting end of the spectrum were open to the idea that thinking about and conducting the process of baking a cake could include CT elements, such as the concept of an algorithm; faculty towards the discerning end of the spectrum argued that there is a distinction between a simple "step-by-step process" and a "precise algorithm," and claimed that additional care might be needed to ensure that an activity like planning out baking a cake tapped into true CT ideas.

This strictness spectrum ranges from "accepting" to "discerning." The "accepting" end of the spectrum represents the viewpoint that a wide range of activities can be considered CT activities, and that participating in those activities will be productive for CT learning. An example of this end of the spectrum is the idea "Even baking a cake is computational thinking!" that was discussed at length while participants were talking about their conceptualizations of CT. This statement suggests that applied activities which could be thought of as involving CT practices are in fact CT activities. In this case, the act of baking a cake requires following a list of steps, and therefore can be thought of as "doing CT" because it relates to using algorithms. Instructors operating from this viewpoint would likely welcome a wide range of CT activities for use in their classroom, including "unplugged" activities not requiring the use of a digital device, and generally have a higher tolerance for what "counts" as a CT activity.

The "discerning" end of the spectrum, on the other hand, represents the viewpoint that only certain, carefully-chosen and -presented activities can be considered productive for learning about CT, and that participating in these activities will help participants learn about CT but participating in other activities will not be as productive for learning. An example of this end of the spectrum was the instructor who commented that she would want to further break down the ecosystem activity with wolves, grass, and sheep growth with her students to "think about the elements present like decomposition." For these instructors, for something to count as a CT activity, the CT practices and/or skills present may need to be highlighted explicitly by an instructor, or the activity must itself draw out those ideas throughout engaging with it. In other words, these instructors are looking for activities to meet a more rigorous standard than simply relating to CT practices.

One factor that seemed to play into professors' positions on the spectrum was computer science (CS) background. Some of our faculty had extensive experience with CS, including one member who had worked on a large grant project in CS education. These faculty members tended to land on the more discerning end of the spectrum, and brought up concerns about whether different activities really focused on CT. The concern expressed was that some activities would not explicitly focus on the CT concepts present enough for students to pick up on them or learn about them.

For example, when discussing the Wolves vs. Sheep activity, two faculty members near this end of the spectrum noted that this activity did not seem “overwhelmingly focused on CT,” and that activities like this one could often be used to focus on the CT, or focus on the science concepts involved, but that it was difficult to foreground both. In other words, they felt an activity like this without a careful focus on the CT concepts involved would not be sufficient to help learn about CT. Another faculty member towards this end of the spectrum, who teaches primarily in a CS department, noted that they would want to further break an activity like this down with their students, focusing on elements present like decomposition. This perspective suggests that discerning faculty members might look for activities to be used in a certain way to ensure that students are thinking about CT ideas. Several of these faculty members recommended emphasizing particular elements of the activity, or focusing on particular techniques, to draw out the specific CT-aligned parts. Lower experience with CS tended to land professors at the accepting end of the spectrum. For example, one faculty member with less CS (and generally science education) experience was enthusiastic about every activity mentioned, describing many activities as “useful” and thinking about connections to almost every subject. Another professor with a similar background responded very positively to the Wolves vs. Sheep example, pointing out that it included randomness and stochasticity very well. Viewpoints towards this accepting end of the spectrum tended to see CT as connected to many subjects and viewed many activities as useful for learning about CT ideas.

One of our follow-up interviews was with Lee, an instructor who had previously taught CT-integrated methods courses but was not teaching one in the upcoming semester. She noted that, with a background in CT already, what she found most interesting from the workshop was "learning about other teacher educators' perspectives on CT or where they are in their CT learning… the understanding of CT is wide-ranging, as, you know, what I've read for teachers," alluding to the span of conceptualizations of CT amongst workshop participants. She elaborated, "It just felt like people have very different ideas of what CT is or why it's important for math teachers, or why it's important for teachers… the thing that struck me too, is that some people are like, 'Well, everything is CT.' And then yeah, I was probably more on the other side." This remark provided both an unexpected confirmation that the range of "strictness" was apparent enough in our workshop's conversation for one of the participants to catch on to it, as well as seeing that it is clear enough for someone working in this space to position themselves upon it.

Faculty Implementations

We met with three faculty instructors to discuss their plans to integrate CT within their courses in the semester following the summer workshop. One instructor was not teaching their typical methods course in the school year, so our conversation was more general and abstract; so, we will focus on the interviews with the other two instructors, who were implementing CT integrations actively within their courses.

Lucy

Lucy instructs a combined elementary and early childhood science methods course. The class is small, with 5 students in the current semester and typically not more than 20. Lucy was experienced in teaching elementary and early childhood methods courses, but newer to teaching science methods courses specifically. Based on her commentary in the workshop, Lucy tends to have an "accepting" perspective of CT activities and views it as universally applicable to a wide range of subjects.

With respect to CT, she felt that historically, she had had to focus heavily on physical and earth science because *"so many students didn't have the science- very much science at all in their own education."* Lucy seems to be saying that CT is difficult to integrate within the course because her teacher candidates also need experience with the content they may not have been exposed to in school already. This suggests a tension between including CT in the methods course and ensuring full coverage of traditional content in science. However, she also described CT's application to multiple subject areas:

> *"But that what you learned from Computer Science from computational thinking, like those skills like patterns and sequencing and problem solving, like those types of things that I got from the workshop, like, that's what I need to emphasize, in general, I mean, for my students, because that's what they're going to need those skills with computational thinking skills can be used across all subject areas. So it really fits in with my emphasis on integration into other content areas."*

The above suggests that Lucy also thinks of CT as highly related to the work she was already doing in science methods. When she discussed learning more about CT, she explained how it helped tie concepts together for her:

"Well, I think it really helped me to look at the foundation of everything I'm teaching rather than just like, okay, here's, you know, here's the periodic table or here's how we measure mass, or here's the solar system. Rather, what's important about learning- why is it important to learn that? Aside from the obvious science content. But it gives us the foundation that enables us to think in those ways across other subjects. You know, there's patterns and there's problem solving and sequencing in everything we do, and so it's really helped – thinking about computational thinking has helped me realize that what we do as teachers is enable students to problem solve and use logical reasoning in all areas. Skipping science is unacceptable, because you can integrate it – and those important skills are then reinforced and transferred into all the other areas like math and reading and social- like, everything that we do. It's sort of a skills foundation."

To support what she viewed as an important subject to include in her course, Lucy planned to make CT a week-to-week feature in her course. She planned to bring up *"patterns, problem solving, representation, and sequencing"* every week as her preservice teachers went through different areas of science. As students reviewed different topics, Lucy planned to highlight relevant CT skills.

Lucy self-identified as being newer to learning about CT. This seemed to be partially related to her shifting into teaching the science methods course relatively recently. She described the workshop as *"really good for me to get thinking about it and how I might start introducing it to my own preservice teachers in a way that they will then be comfortable working with their early childhood students."* She had found several websites for resources to do *"sequencing and pattern and representation outside of the screen,"* but hadn't completely decided where all of these activities should go. We might describe this as a "bottom-up" approach not unlike what we will see with our next case study; Lucy appears to look at the activity level for opportunities to use related CT activities and concepts.

Interestingly, Lucy did focus on "unplugged" CT activities, or activities where students are explicitly not using a device like a computer or a tablet. She noted, *"In a sense, it does make a lot of sense to use those with younger kids especially, not just because of the- like, I don't know, I don't want- every first grader shouldn't be like, on a tablet, their whole school day."* Unplugged activities allowed students to engage with CT without needing to be on a device for extended periods of time. Lucy also preferred unplugged activities because of accessibility, noting

> *"Some of these apps, even if they're trying to be simple, it's sort of like… are you putting things to the kids that they really understand? Or is it sort of like, well, as long as you've had some tablet access or some computer access before, you'll do better at this, which I don't love. My kids here in West Baltimore, there's not- they don't even have broadband access. It's a real equity problem. So they especially need time to explore and to learn."*

Overall, Lucy's plan for course integration makes CT a primary course objective as defined by our criteria: her "week-to-week" plan for consistent connections to CT concepts means CT will effectively occupy more than 10 activities throughout the 15-week semester. She leans away from highly technological CT activities, instead favoring "unplugged" activities that can be done without a device or technical app. She attributes this to her population of teacher candidates and the students they will serve having less access to technology. This may also be partially attributable to her role as an elementary and early childhood teacher educator, as she expresses a desire to avoid having young students on a screen all day, and CT can be included in a more general way at this age level, establishing a foundation for more technical applications of concepts in the later grades. In addition, one of Lucy's beliefs expressed in her interview is that she views CT as universally applicable, not only to different topic areas within science but also to different subjects like reading, math, and social studies.

Steph

Steph also instructs an elementary science methods course, though at a different university than Lucy. The course she teaches tends to be larger than the one in Lucy's program, at around 40 students. A relevant experience for Steph is her past and current involvement in research projects on computer science/computational thinking and STEM subjects, which may at least partially inform some of her thoughts on CT and its usefulness in STEM education. Based on her commentary from the workshop, Steph holds a viewpoint closer to the "discerning" end of the strictness spectrum than does Lucy, as she often felt activities would need to be introduced properly or talked about in a way that explicitly highlights the CT elements present. Despite coming from a different background and holding a different viewpoint on what "counts" as a CT activity, Steph's implementation looks similar to Lucy's, as we will see below from her activity-focused, bottom-up plans for CT integration.

Steph predominantly described her learning from the workshop as helping her better understand how her work around CT differed from other efforts. She described many of the approaches she's seen as

> *"introducing CT to teachers… in a top-down sort of approach, where CT experts come in, and they teach the teachers: okay, here's what computational*

> *thinking is. Here are some strategies and elements. Here's some examples. Now let's find places in the curriculum where we can integrate it."*

In contrast, she noted that in a research project she is working on,

> *"We're basically developing heuristics, guiding principles, for modifying existing science curricula to include computational thinking – to modify it to include computational thinking and computer science. And the approach we're taking with this is an RPP [researcher-practitioner partnership]. So we're working with teachers and other experts, and taking sort of a bottom-up approach. We look at where, like, computational thinking seems to either already fit, or already be present, even if it's just the seeds of it in any given lesson or activity, and sort of learn about it, make sense of it and use it in an applied way in the moment."*

It seems that what Steph remembers from the workshop is first and foremost this strategy, which offers up individual CT-integrated STEM activities for teacher candidates to experience, allows them to brainstorm about what they just saw first, and only then introduces them to formal definitions of CT and its domains. In our work in the module as presented in the summer workshop, we refer to this strategy as "Experience First, Formalize Later," (Stats Medic, 2018) where teacher candidates are introduced to CT activities before they are introduced to any formal frameworks on CT (Moon et al., 2023). For Steph, this style of introduction to CT seems to be memorable, probably because it resonates with her own experience working with teachers on how to use CT in the classroom.

Steph gave an example of an activity she uses in class that highlights her "bottom-up" introduction to CT. In this example, teacher candidates complete a survey to measure their own individual plastic waste generation over time and find a daily average. Steph expands on this activity in class by asking,

> *"How can we make sense of this at scale? How can we estimate how much plastic trash all the undergraduate students in the country throw away? And I just gave them that problem. And then they solved it. And then we asked, What did you do? Okay, so this, you decomposed it, you broke it down into different components, and then you developed algorithms, like based on the class average, to find out- and that helps us make sense of this issue in different ways. And then using different ways to leverage computers, or computing devices to help us."*

While Steph explicitly states several domains of CT that she expects students to use during this work, she adds specifically, *"I don't care so much that they are able to name the steps, like if they don't know abstraction from decomposition."* This approach seems closely aligned with the Experience First, Formalize Later (Stats Medic, 2018) format that we employed in our course module and the accompanying workshop: this course activity is meant to give students the chance to use CT skills in context in a relatively informal way, without needing to name the skills they are using or describe them in detail. However, students are still gaining knowledge about these skills, and CT in general, through this use and the class can circle back later to formalize terminology and knowledge around CT.

However, she also maintained a position from her time in the workshop that not every activity tangentially related to CT was productive for learning about CT, continuing to land her rather decisively at the "discerning" end of our strictness spectrum:

> *"I don't want to communicate to teachers that everything you do is computational thinking, because I don't feel like that. I feel it's a little disingenuous… I don't want to risk the integrity of what computational thinking is, and what work it can do for us, by just kind of lumping any list of steps as an algorithm… but looking at okay, to solve- how can we solve this problem? And then, let's look at what we did. And then can we take those*

steps and apply it to a different problem… So we're using it to help us."

Here, Steph appears to indirectly reference a discussion from the workshop which we believe to be representative of broader conversations about CT: whether lists of steps are sufficient to be defined as algorithms in learning about CT. This is one moment where there is a clear difference in her approach to Lucy's. Where Lucy sees universal application of CT, and considers a wide range of activities for inclusion in her course, Steph wants to limit what she labels CT and only include activities that seem to uphold the "integrity" of CT. Her explicit statement that she does not want to communicate to teacher candidates that "everything is CT" appears to be in contrast with the view that CT is in everything. Instead, Steph appears to think of CT as more generalizable instead of universal: while it may not be present in every activity, the same strategies used to solve one problem may have numerous applications in different contexts. The difference is subtle but may result in teacher candidates learning from each instructor walking away with slightly different conceptions of how and where to introduce the subject.

Steph did note that working with pre-service and in-service teachers on CT learning may require a different approach, which aligns well with our understanding of PFL literature. Steph summarizes the challenge of finding time for CT in a course for pre-service teachers, where the methods course has a multitude of priorities to manage simultaneously:

> *"Pre-service teachers deserve to at least have access to [instruction on CT]. Or, an introduction to it. Because their students also deserve that. So, from that sense, I feel like it's important… But the other thing is that there's so*

> *much that is required of this course… like being able to interpret and use NGSS materials to actually use the standards and understand what you're looking at when you see it… to their understanding, like, of basic science content, stuff they're going to be using and dealing with when they're- as teachers. And most of them don't have science backgrounds… so it's not really feasible to spend a disproportionate amount of time on [CT], in the same way I wouldn't spend, you know, like we have our content module stuff. And we spent three weeks on Earth Science… three weeks on Physical Science… so integrating CT where it fits in and seems like it's productive… but not trying to force it in."*

Here, Steph notes that many science basics need to be covered with pre-service teachers, who can't be assumed to have previous sufficient knowledge of the material to skip content modules. She notes that introducing them to CT is important, but that with multiple other competing priorities, CT will only be integrated in this kind of course where it seems like it will be productive. In contrast, she notes that courses for in-service teachers have greater flexibility:

> *"As far as our in-service teachers in the master's program… that's different. In that course, it's going to be more appropriate to do more explicit, like CT for CT's sake stuff, with teachers getting a master's degree in, in this sort of specialization stuff… It's not as big of a lift to ask them to engage in some of this stuff because of… like the cognitive load, like everything they're being asked to learn right now for the [pre-service] teachers. It's so much."*

With this response, Steph posits that the goal for pre-service teachers should be to give them a basic introduction to CT so that they are aware of its existence and where it can be productively supportive in teaching science. She suggests that focusing more heavily on CT is only appropriate for teachers taking the extra degree to specialize in advanced techniques in teaching science. This seems compatible with the PFL perspective as it applies to teacher education because the initial degree is viewed as basic preparation for teaching, not the end-all-be-all of what teachers will ever learn about teaching. Enough information is provided about CT so that teachers can get a feel for it – perhaps without even getting the names of domains right, and certainly without the expertise to apply it constantly throughout a curriculum – with some expectation, as Steph describes, that those returning for a specialized degree in education will be prepared to dive into CT in greater depth and learn more about it.

Steph notes that her implementation is limited in scope, saying, *"To be honest, this is the first year that I'm doing it like this. So it's in progress."* This seems to be positive when viewed through the PFL perspective, now at the faculty instructor level. With CT-integrated activities like the plastic waste example, Steph is demonstrating to teacher candidates how CT can be used to enhance an activity where it is suitable, in a measured way where it is what she calls a "theme" of the course, but not overwhelming other learning needs of her teacher candidates. What appears promising for future development of the course is that she is actively

> *"looking for ways that computational thinking can help elevate the sustainability piece in science, and scale and proportion seems to be a big one… using computational resources to figure out those broader impacts where it's hard to visualize that in the scope of a classroom."*

Thinking in this way is demonstrably leading Steph towards suitable integrations of CT in her methods course rather than employing it where it doesn't belong. Over time, we expect this to be a more sustainable outcome that results in more effective instruction on CT integrations for teacher candidates.

Discussion

This study looked at conceptualizations of CT among faculty instructors who participated in a summer workshop on how to integrate CT within STEM methods courses. We found three main conceptualizations of CT – (1) that it is a means of describing a natural set of problem-solving skills that people already do, (2) that it describes a set of technical, consciously-used skills distinct from general problem-solving, and (3) that it serves to introduce learners to the cultural context of computer science. We also noted a spectrum of "strictness" around what "counts" as a CT activity. In examining two case studies of instructors who participated in the workshop and taught CT-integrated methods courses, we noticed that despite coming from different backgrounds, their implementation profiles looked roughly similar, with a bottom-up approach focused on modifying specific activities. However, subtle differences in their viewpoints may result in their teacher candidates using CT in the classroom in different ways.

Our results indicated a wide spectrum of "strictness" about CT activities. Clearly, not every faculty member agrees about "what counts" or qualifies when it comes to CT activities. While this might initially seem to set up some discordance about how to instruct teacher candidates about CT, we posit that there are ways in which this spectrum might be helpful. The difference in perspectives seems to be generally suitable for grade level, as students in lower grade levels may not require quite as specific understanding of CT, so a broader range of activities could be useful in introducing them to the concepts. Their teachers need faculty instructors that are open to a broader range of CT activities, as at this stage they are just “setting the stage” for later CT learning. Meanwhile, more discerning instructors preparing teacher candidates to teach higher grade levels might lead to particular activities being used for more technical CT learning outcomes, which is increasingly important for middle and high school students. Because of the limited size of our workshop, it was difficult to tell how well this divide played out. At least one instructor who works with secondary teacher candidates had a “discerning” viewpoint; the only other instructor who indicated explicitly that they worked with secondary teacher candidates self-identified as being new to CT and not really knowing what it was. Steph stands out as an example of an instructor for elementary teacher candidates who does not have an “accepting” view of CT, though several other instructors who work primarily with elementary methods did express that view. A more focused study of how these viewpoints align with grade level of prospective teacher candidates might help to shed a clearer light on this matter.

A spectrum of ideas about what counts as CT might also lead to a spectrum of ideas about noticing CT in the classroom. It is probably helpful for teacher candidates at lower grade levels to notice CT ideas being expressed in their nascent form, and those at higher grade levels to be looking for ideas closer to “formal” CT concepts. Again, the connection between grade level of methods instruction and position on this spectrum would generally work in our favor, but more data would be necessary to confirm this pattern (particularly from instructors of secondary teacher candidates).

Findings about these different views on CT and CT activities suggest a need for leadership in STEM education departments to think about how they will introduce and develop teacher candidates' understanding of CT throughout their STEM education program. One strategy could be to lead with more open integrations with a wide range of CT activities in earlier coursework with the goal of opening teacher candidates' minds to many possibilities early on. Later, after teacher candidates build familiarity with the subject, courses could ask them to make more discerning decisions about which CT integrations feel productive to guide their focus and time. Teacher educators from across the "strictness" spectrum could thus be an asset to candidates by sharing their perspectives at strategic times. Another possibility could be to alternate accepting and discerning viewpoints on CT so that candidates walk away understanding both perspectives and the benefits of each: namely, that many problem-solving behaviors that students display could be linked to CT, but also that certain CT activities may be more specifically useful for developing particular technical CT skills or practices.

For designers of PD experiences on using CT in teacher education, we provide evidence that a one-off workshop may lead to significant changes in practice among "ready-to-learn" teacher educators. Lucy and Steph provided two interview case studies for faculty instructors integrating CT into their methods courses. For Lucy, the CT workshop provided a shift in mindset to view CT as supportive of learning about other topics in science. This mindset led her to look for opportunities to connect CT to other science topics throughout the course, solving her existing problem of trying to find time to fit CT in amongst many other topics in science that she felt her teacher candidates needed. As Lucy self-identified as feeling newer to CT and its applications in science, this workshop gave her the confidence and new ideas to begin this process. For Steph, the CT workshop provided an impetus to plan activities for her methods course that integrated relevant CT activities. The workshop also gave her time to plan a particular activity in which students develop algorithms and use computing tools to estimate projected plastic waste generation in a state or country based on data collected within their class. Steph also works on an RPP that works alongside teachers to help integrate CT where it feels productive, so looking for specific opportunities to work in CT into science methods may be a familiar method. In addition, she mentioned a specific interest in teaching about environmental science and sustainability that may explain the topic she selected for a CT-integrated lesson.

Despite Lucy tending towards a more "accepting" view of CT activities and Steph favoring a "discerning" view, their integration of CT within their elementary science methods courses still shared many commonalities. Both Lucy and Steph employed a largely "bottom-up" approach to CT integration, emphasizing CT concepts when they were related to the topic being covered through modified class activities. Lucy seems to prioritize teacher candidates' familiarity with general concepts of CT, like patterns and sequencing, over knowledge of specific terminology (e.g., PRADA (Dong et al., 2019)); despite expressing a discerning view of CT activities in the workshop and even within our interview, Steph largely shares this approach with pre-service teachers, noting that their precise ability to name different

CT concepts is not a priority at that stage in teacher development. Instead, she shares a view with Lucy – that these pre-service teachers need to have a firm command over the scientific topics they will be responsible for teaching and may not have gotten full exposure to in their own schooling – and suggests that CT is somewhat of a bonus, and a higher priority for those in-service teachers who return for a specialized degree in science education.

PD designers for CT in teacher education should consider these findings as generally positive because teacher educators who shared their implementation profiles with us did them in unique ways aligned with their own goals for their methods courses; however, both integrated CT in a way that supported teacher candidates' learning in their methods course. This suggests that even PDs with short duration may have significant impact on teacher educators' practice with regards to CT. A particular driver of this impact in this workshop may have been the time given during the workshop for teacher educators to start to build their plan for fall implementation and discuss it with colleagues. We would additionally suggest that in this style of workshop, or longer-form PD on CT in teacher education, time for reflection on learning about CT would be a valuable inclusion. This could help teacher educators clarify their own positions about where they feel CT is most useful in their methods course and other areas, and also provide more knowledge to designers about how their PD sessions affect teacher educators' views on CT.

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Chapter 5: Conclusion

CT is potentially supportive of mathematics and science learning when integrated within lessons in those subjects. However, studies indicate that this integration needs to be carefully implemented (Fofang et al., 2020; Schanzer et al., 2015), and that many programs to prepare teachers to use CT are inadequate (Cabrera, 2019; Munasinghe et al., 2021). This suggests a greater need for math and science teachers well-prepared to use CT in the classroom. Since there is currently no inclusion of CT within teacher education on a large scale, we see a necessity for more modular materials to integrate CT within mathematics and science methods courses, or similar courses for math & science teachers.

This dissertation investigated the effects of a new module designed to be integrated within these courses for teachers, which emphasizes an Experience First, Formalize Later (Stats Medic, 2018) approach. In Study 1, I investigated knowledge teacher candidates held about CT and how that knowledge evolved over the course of interacting with the module activities. I found that participants' conceptualization of CT expanded to include a wider variety of skills and practices related to CT. I conclude that this experience-first module tended to give participants active knowledge of integrating CT within their disciplinary lessons that is flexible to their particular interests.

Study 2 analyzed two case studies of teachers who had previously participated in the module and how they used CT knowledge to integrate related skills and practices within lessons for their class. While we found that some knowledge teachers associated with CT was not that which had been intended from the module, we found that this knowledge nonetheless led to productive classroom practices, and our second case study, Eileen, demonstrated a reliable tendency to bring CT knowledge from the module directly through to classroom practice. This finding was especially positive when viewed from the PFL (Bransford & Schwartz, 1999) perspective, since being able to use one practice within CT productively suggests a teacher who deeply understands the productivity of one area that will eventually be able to expand the scope of their CT integrations, as opposed to a teacher with a wider but more surface-level understanding of multiple areas who may not be ready to integrate CT productively in any domain.

Study 3 examined the effects of a CT workshop on faculty implementations of CT within their methods courses. We first discuss conceptualizations of CT among the instructors who participated, including the definition of a "spectrum of strictness" referring to how different instructors felt about what "counts" as a productive CT activity. Instructors did not agree about whether several kinds of CT activity, including both "plugged" and "unplugged" activities, would be productive for student learning on the subject. Using interviews with instructors after the workshop, we analyze planned implementation profiles for the fall semester, noting small but productive changes to their methods courses. Again using the PFL perspective, we argue that this is a positive move, as a limited scope of productive changes bodes better for the future of these courses than a grander scale with less care about the productivity of the changes.

Takeaways

Scope of Knowledge from Qualitative Study

Quantitative evaluation of CT learning has dominated most research on CT in teacher education. This is largely due to generative and inspirational work by Yadav and colleagues (2014), which included a battery of Likert-scale questions to assess outcomes from a CT learning experience. However, what we see in the results of these studies suggests that this quantitative evaluation, while useful, is not entirely sufficient. Teachers and instructors alike displayed a wide variety of knowledge about CT that would not be fully described by ratings on these questionnaires. The ability to follow up on ideas within an interview, and the flexibility of the inductive coding (Thomas, 2003) approach in describing what teachers were saying, gave a much more detailed picture of how our focal teachers were using knowledge about CT in the classroom. Similarly, this approach led us to identify subtle differences in the way instructors looked at using CT for their methods courses and what they felt would lead to productive CT learning.

We do not suggest that quantitative methods have no place in evaluating the materials used to include CT in teacher education. Instead, we suggest that more work ought to focus on a mixed-methods design, using quantitative methods as an overall evaluation of the teaching materials and qualitative analyses as a more in-depth look at the knowledge of the teachers and instructors involved. Study 2 exemplifies this need: both teachers self-described as not remembering much about CT and then proceeded to discuss a significant body of knowledge about CT; however, the knowledge they held was different in potentially important ways. Asking these teachers to respond to a Likert-scale item measuring their knowledge of CT would have likely resulted in low scores for both teachers, suggesting that they remembered nothing about the subject. This misses both the fact that the learning module clearly did impart some useful knowledge, and that the two teachers held subtly different knowledge about CT. Those subtle differences, like one teacher's focus on classroom practices while the other focused more on algorithms, are what we should focus on when considering how to modify the module for future uses but would be entirely missed in a purely quantitative evaluation of our materials.

CT Opens the Door for Productive Practice

One of the findings in Study 2 was that one focal teacher associated CT mostly with classroom practices such as student choice when solving problems, group discussion work around tasks, and using culminating activities to revisit multiple ideas from a unit on a particular problem. This is not the knowledge we intended to include in our module; however, these are generally productive classroom practices for a math class. This aligns with a finding from Walton & Walkoe (2021), which suggests that teacher candidates used more ambitious math practices and focused more on student understanding after CT instruction. While it is not necessarily the outcome we sought, it nonetheless led to a productive outcome: ambitious math practices are not always easy to prepare candidates to use. I believe there is still something particularly beneficial about math and science teachers using genuine CT skills and practices to enhance their lessons, but it is comforting to know that even if they are not learning exactly what we hoped they would learn, the module still appears to be supporting the development of strong teaching practices.

Range of Conceptualizations of CT

All three studies suggest a wide range of conceptualizations of CT. This was true for teacher candidates at the beginning and end of the module in Study 1, our two teacher case studies in Study 2, and the instructors who participated in Study 3. Initial conceptions of our teacher candidates included those associated with known domains of CT, less-related concepts like calculation and logical thinking, and some null responses indicating a general unfamiliarity with CT. Knowledge expressed in our case study interviews in Study 2 included the subjects of pattern recognition, abstraction, decomposition, and algorithms as expected from PRADA (Dong et al., 2019) but also unexpected classroom practices like giving students choice of solution methods, having them work in groups, and using CT as a culminating review activity. Even our instructors in the workshop in Study 3, almost all of whom self-identified as having some formal experience with CT, had moderate disagreements about what CT was, whether those skills and practices were the same or distinguishable from general problem-solving, and what counted as a productive CT activity. The general takeaway here is that at every level, and even among individuals experienced with the subject, there is not a single agreed-upon definition of CT. In many cases, conceptualizations were so different as to be incompatible with each other.

This is an issue that researchers on CT in teacher education will need to consider as designs for courses and learning materials continue to develop. Certainly, not all teacher candidates are on the same page about CT from the beginning, but the discrepancies in the knowledge expressed by our classroom teachers after the module suggest that designers need to account for inconsistencies in how teachers interact with, organize, and use knowledge from their CT learning. Additionally, the differences in viewpoints expressed by instructors means that even several people devoted to including CT in teacher education may design or enact curriculum on the subject in radically different ways.

I would like to stress that the burden of a "desired outcome" when including CT in teacher education should not rest on the teachers participating in learning activities. I view any evaluation of our learning module as critical of the module materials themselves, and not of the teacher candidates and teachers who take knowledge – not always the knowledge we intended – away from this experience. Teachers are inundated with a multitude of ideas about what it means to teach, educational and PD experiences offering up new ideas and techniques to better their practice, and policy at different levels of educational administration and government pushing and pulling them in different ways. If our goal is to have teachers walk away with particular desired outcomes, then we need to offer convincing evidence, intelligible and helpful materials, and clear applicability to the job. Any evaluation of learning materials reflects back on the creators and what we have created.

Experience-First Approach and PFL Perspective

A novel element of this CT module was the experience-first design, in which teacher candidates participated in CT activities and brainstormed what they thought CT is before being introduced to academic frameworks on CT in math and science. The results of Study 1, in which teacher candidates' knowledge about CT changed over the course of the module, and Study 2, in which two classroom teachers used knowledge from the module after several months had passed, suggest that this design helped give CT knowledge some staying power. The experience-first design should be considered for other curriculum designers in CT as well as other subjects, as it may prove more effective in the long run than traditional designs.

This design appeared particularly effective when viewed from the PFL (Bransford & Schwartz, 1999) perspective. This perspective suggests viewing learners – in this case, teacher candidates – not as finished with their learning when they leave a learning experience, but rather being prepared for additional learning that they may do in the future. This is a useful mindset when thinking about CT, and other subjects where new technologies, activities, and curricula are still being developed because we do not want teachers to be done with their learning *now* – instead, we want them to understand how new knowledge may fit into their existing understanding of the subject so that they can continually build on their present knowledge for use in the classroom. Participants in Studies 2 and 3 were ready to integrate CT in a productive way within specific course lessons or activities, suggesting that they would be well-prepared to integrate similar information in the future as it is developed or as they interact with it.

Future Directions

Continued Qualitative and Mixed-Methods Evaluations of PD and Courses CT Knowledge

These studies provide an in-depth analysis of CT knowledge at several levels and following different learning experiences, using qualitative methods like video analysis, interview analysis, and artifact analysis using course submissions. As mentioned, some of these analyses yielded a nuanced understanding of what turned out to be rather complex organizations and uses of knowledge beyond what a simpler multiple-choice item response could have provided. In general, these qualitative analyses could offer enlightening insights to supplement existing quantitative methodologies to assess the efficacy of CT learning materials for teachers.

I hope that mixed-methods evaluations of CT learning materials will become the standard because I believe every curriculum developer in this field could benefit not just from a simple answer to the question "did this result in the learning we intended," but also an answer to the more complicated question "*why* did this result occur?" With greater use of these qualitative and mixed-methods designs, we can build greater understanding of how and why learning about CT happens among teachers, and how that knowledge gets used in their lessons.

Module Deployment and Evaluation on a Larger Scale

One of the main contributions of this project was the development of a module designed after the Experience First, Formalize Later approach (Stats Medic, 2018). Based on a small sample of teacher candidates, some of whom we were able to follow up with after the module in Study 2, this seems to be a productive and helpful approach. However, it would be useful to see this module deployed on greater scale and with a wider variety of teacher candidates. I hope to see these materials being used in other contexts, as I believe they will support other instructors interested in including knowledge on CT in their methods courses. I am interested in seeing what learning it brings to other candidates, and whether that is similar or different to what we have already seen based on instructor, university context, program context, and other factors.

Impact of Different Instructors' CT Implementation Profiles

Study 3 grants insight into the diverse conceptualizations of CT and feelings about what makes for a productive CT activity at the teacher educator level. I believe teacher educators are an important population to follow up on if CT in teacher education is going to continue to develop at scale because, to prepare many math and science teachers to use this in their practice, we will require a much larger population of CT instructors to teach them. Future work could include several related lines of research. One would be how a broader sample of teacher educators respond to learning experiences like our CT workshop. Another would be how different prior experiences are associated with different teacher educator views on CT. Study 3 indicates that not all teacher educators agree on different aspects of CT and why it matters, or how to teach it productively, but we do not have enough information to understand where these differences come from. Finally, I hypothesized that the so-called "spectrum of strictness" could be beneficial if teacher educators at different levels introduced their teacher candidates to mindsets about CT integration appropriate for the developmental level of the students they would be teaching. Now that we have mapped this range, it would be useful to know more about its impact. Research on how this plays out in practice – whether teacher educators with a more "accepting" mindset towards different CT activities might prepare teachers for younger grade levels to use a more open mindset in introducing the subject and noticing their students' CT skills and practices, and whether those with a more "discerning" mindset might help teachers for older students look carefully at the activities they use to ensure that there will be specific and productive learning outcomes – would serve to expand our knowledge both of how different mindsets on CT in teacher education prepare teachers in different ways, as well as how they can prepare teachers to serve students.

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Appendix A: Student Survey

1. How would you explain the concept of “computational thinking”? (open-ended)
2. Can computational thinking be integrated into the classroom? If yes, how would you implement computational thinking into the content area you plan to teach? If no, why can’t computational thinking be integrated into the classroom? (open-ended)
3. Computational thinking is understanding how computers work. (Likert, 1-5)
4. Computational thinking involves thinking logically to solve problems. (Likert, 1-5)
5. Computational thinking involves using computers to solve problems. (Likert, 1-5)
6. Computational thinking involves abstracting general principles and applying them to other situations. (Likert, 1-5)
7. Computational thinking can be incorporated in the classroom by using computers in the lesson plan. (Likert, 1-5)
8. Computational thinking can be incorporated in the classroom by allowing students to problem solve. (Likert, 1-5)

Appendix B: Instructor Interview

1. What course are you teaching in fall that we're talking about today? Who normally takes the course? How many students are in it this semester?

2. What did you learn about CT from our summer workshop?

3. How different is instruction on CT from what you were already doing, or from the core goals of the course?

4. What are your plans to integrate CT in your methods course this fall?

5. Are there specific activities that you have chosen to include in your methods course to help integrate CT? How many activities have you chosen or modified to do this?

6. Have you modified the structure of the course to include CT? If so, how?

7. Are there any other modifications to your plans for instruction that you think will help you integrate CT?

8. How do you plan to evaluate what students have learned about CT?

Appendix C: Instructor Survey

1. In your own opinion, do you think you have integrated computational thinking into this course? (Y/N)

2. In the course you are teaching this semester, do you have a unit (here considered 3-5+ lessons) devoted to computational thinking? (Y/N, with an optional space to clarify response)

3. Have you modified 10 or more activities in this course (class activities and/or assignments) to incorporate computational thinking? (Y/N, optional space to clarify)

4. Are 9 or more classroom hours in your course devoted to computational thinking? (Y/N, optional space to clarify)

5. Please rate your agreement with each of the following statements (all Likert, -2/Totally Disagree to 2/Totally Agree):

    a. K-12 math instruction would be better with computational thinking integrated lessons.

    b. K-12 science instruction would be better with computational thinking integrated lessons.

    c. It is important for K-12 math teachers to learn about computational thinking.

    d. It is important for K-12 science teachers to learn about computational thinking.

e. Computational thinking is similar in discipline to mathematics.

f. Computational thinking is similar in discipline to science.

g. I know what computational thinking is.

h. I know how to integrate computational thinking in my course.

i. I can learn more about computational thinking if I want to.

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