ABSTRACT

Title of Dissertation: COMPUTATIONAL THINKING IN THE ELEMENTARY CLASSROOM: HOW TEACHERS APPROPRIATE CT FOR SCIENCE INSTRUCTION

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Researchers and policymakers call for the integration of Computational Thinking (CT) into K-12 education to prepare students to participate in a society and workforce increasingly influenced by computational devices, algorithms, and methods. One avenue to meet this goal is to prepare teachers to integrate CT into elementary science education, where students can use CT by leveraging computing concepts to support scientific investigations.

This study leverages data from a professional development (PD) series where teachers learned about CT, co-designed CT-integrated science lessons, implemented one final lesson plan in their classrooms, and reflected on their experience. This study aims to understand how teachers learned about CT and integrated it into their classroom, a process conceptualized as appropriation of CT (Grossman et al., 1999).

This dissertation has two parts. The first investigates how teachers appropriated CT through inductive and deductive qualitative analyses of various data sources from the PD. The findings suggest that most teachers appropriated the labels of CT or only Surface features of CT as a pedagogical tool but did so in different ways. These differences are presented as five different profiles of appropriation that differ in how teachers described the activities that engage students in CT, ascribed goals to CT integration, and use technology tools for CT engagement.

The second part leverages interviews with a subset of teachers aimed at capturing the relationship between appropriation of CT during the PD and the subsequent year. The cases of these five teachers suggest that appropriation styles were mostly consistent in the year after the PD. However, the cases detail how constraints in autonomy to make instructional decisions about science curriculum and evolving needs from students can greatly impact CT integration.

Taken together, the findings of the dissertation suggest that social context plays an overarching role in impacting appropriation, with conceptual understanding and personal characteristics coming into play when the context for CT integration is set. The dissertation includes discussions around implications for PD designers, such as a call for reframing teacher knowledge and beliefs as part of a larger context impacting CT integration into schools.

COMPUTATIONAL THINKING IN THE ELEMENTARY CLASSROOM: HOW TEACHERS APPROPRIATE CT FOR SCIENCE INSTRUCTION

by

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Dedication

Para mi abuelo César y mi abuela Elisa.

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CT	Computational Thinking
DBR	Design-based Research
PD	Professional Development
STIG^{CT}	Science Teaching Inquiry Group for Computational Thinking

Chapter 1: Introduction

In a world increasingly permeated by computational devices, Computational Thinking (CT) is considered a key skill for young learners. Although characterized in multiple ways by different scholars, most definitions of CT converge on the concepts of computational abstraction, algorithmic thinking, conditional logic, and systematic error detection, among others (Grover & Pea, 2013). While its roots belong in the field of computer science, CT has recently been posed as an important learning objective for all K-12 learners—especially in STEM (National Science and Technology Council, 2018; NGSS Lead States, 2013). In order to fulfill the integration of CT into K-12 schooling, researchers call to prepare teachers for proficiency in computing, CT, and its pedagogical applications (Barr & Stephenson, 2011; Yadav et al., 2017). In response to this demand in teacher preparation, numerous efforts are underway to help teachers understand CT and integrate it effectively in their instruction. Empirical research on this area typically describes the types of educational experiences that teachers participate in (Chang & Peterson, 2018; Hestness, Ketelhut, McGinnis, Plane, et al., 2018), how teachers grow to understand or conceptualize CT (Gadanidis et al., 2017; Lamprou & Repenning, 2018; Mouza et al., 2017; Sadik et al., 2017; Yadav et al., 2014), their intentions and confidence to integrate CT in their practice (Adler & Kim, 2018; Bower & Falkner, 2015; Cabrera, Ketelhut, Hestness, Mills, & McGinnis, 2019), and teachers' perceptions on the benefits and obstacles of integrating CT into their teaching (Nickerson et al., 2015).

In essence, these studies aim to understand how teachers participating in different educational experiences change their beliefs and understanding around CT. Together, the field seems to make the reasonable assumption that teachers who have a sophisticated understanding of CT, believe in its value for education, and have the necessary resources to integrate it in their classrooms would effectively change their practice to comply with the calls for CT in their teaching. However, few studies examine the link between teachers' beliefs and understanding of CT and their classroom practice (see Israel et al., 2015 and Rich & Yadav, 2019 for exceptions).

Instead, most studies examine teacher preparation around CT by capturing their experiences in the contexts of the university classroom or professional development (PD) sessions where the teacher *learns*, without connecting that learning to classroom where she[1] *teaches*. Therefore, while the extant literature is valuable to understand the process by which teachers develop knowledge and beliefs about CT, it limits our ability to make claims about how those changes are applied in the classroom—which, in turn, are assumed to produce effects in student learning (for an example of this relationship in Math, see Desimone, Smith, & Phillips, 2013; Firmender, Gavin, & McCoach, 2014).

One way to conceptualize these changes in practice is through the theoretical framework of appropriation of pedagogical tools (Grossman et al., 1999), which describes different levels of appropriation that teachers may show when taking a new pedagogical innovation (in this case, CT) to their classrooms. While this framework posits that specific factors—such as the social setting of learning, the personal goals and motivations of the teacher, and her knowledge and beliefs about the content—can affect the appropriation of the new practice, the specific ways in which these factors affect CT implementations is unknown. Therefore, by capturing teachers' reflections on their practice implementing CT-integrated science lessons and incorporating multiple data sources about teachers' beliefs and understanding around CT, this study seeks to answer the following research questions:

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[1] Throughout this document, I refer to participants using the pronouns *she*, *her*, and *hers*. I base this decision on the demographic composition of the elementary school teacher workforce—which is primarily women. However, my use of pronouns does not indicate that the study focuses on women or does not apply to teachers who do not identify as women.

1. How do teachers participating in a CT-focused PD program appropriate CT to integrate it into their science teaching?
2. How do different types of CT appropriation correspond to teachers' reflections of their CT integration within their classrooms?

The dissertation, conceptualized as a holistic multi-case study (Yin, 1994), is divided into two parts—each corresponding to a research question. To answer the first question, I draw from multiple sources of data including videos of teachers co-designing CT lessons with researchers, their reflections during PD around CT, assessments of CT understanding, surveys on their self-efficacy around integrating CT into science instruction and focus groups on CT integration. To answer the second question, I draw on a series of in-depth interviews with a subset of participants. These interviews focused on CT integration: how teachers designed, implemented, and reflected on CT-integrated science lessons after their participation in PD.

Drawing from these sources of data, the study focuses on teachers' PD participation and classroom implementation to understand how teachers appropriate CT for their classroom instruction. As stated above, I use a theoretical framework of teacher appropriation of pedagogical tools (Grossman et al., 1999) to guide this study. This framework describes how teachers adopt a new pedagogical tool in five increasingly sophisticated levels of appropriation. The level a teacher reaches is determined by their conceptual understanding of the pedagogical tool, their personal characteristics, and the social context of their learning.

The findings from answering the first research question show that teachers appropriate CT for science instruction in varied ways, which are not necessarily organized in a hierarchical list of appropriation levels as Grossman et al. suggest. Instead of describing appropriation as a linear progression based on an increasing conceptual understanding of the pedagogical tool, this study suggests that appropriation differs in other dimensions such as the goals ascribed to CT in the classroom, the degree of science integration, and the tools teachers use for implementation. These variations of appropriation are better described as qualitatively different profiles of appropriation than as hierarchically organized levels.

While the framework of appropriation authored by Grossman and colleagues names the social context of learning as a factor that can impact appropriation, this study provides a more nuanced understanding of *how* that influence takes place. Specifically, my findings suggest that the context where teachers work—their school culture, peers, and administration—are highly influential on how teachers appropriate CT. In fact, the data suggest that context may serve as a gatekeeper of opportunities for planning and implementing CT while conceptual understanding and beliefs can exercise influence on CT integration only in certain contexts.

The dissertation is organized in multiple chapters to give the study and its findings a cohesive structure and facilitate readability. First, in Chapter 2, I explain the motivation for the study and the need to understand how teachers appropriate CT for their science instruction. I also provide a review of existing literature around CT and teacher education to situate my study and highlight the gaps in understanding that the dissertation contributes to. In Chapter 3, I detail the methods of the study, including the context of the PD that teachers participated in, data collection and analysis procedures, and descriptions of the teachers in the study. Chapter 4 is the first findings section where I describe the results of the group-level analysis I conducted to respond to the first research question. This chapter also includes a discussion of those findings, including implications for teacher education. Chapter 5 contains a second set of findings, this time related to the second research question and based on the case studies. Here, I provide an in-depth analysis of the cases as a group as well as a discussion of their implications for the framework of appropriation and our understanding of the relationship between teachers' PD participation and their integration of CT in the classroom. In Chapter 6, I provide a brief discussion that connects the findings from both parts of the dissertation and to the literature on teacher education. This section also lists different limitations and lingering questions from the study. Finally, I provide a set of conclusions in Chapter 7.

Chapter 2: Motivation and Literature Review

To explain the motivation for this study, I seek to explain (1) the importance of integrating CT into wide-reaching formal education to prepare our students for an increasingly computational future; (2) the rationale behind aiming this intervention at the elementary level; and (3) the purpose of focusing on teachers when *student* learning is the CT movement's ultimate objective (Grover, 2018).

A Growingly Computational World

One of the main reasons to integrate CT into K-12 education is the increasingly computational nature of our society. As computers become more powerful, widespread, and affordable, their applications broaden from the management of entire city-wide traffic systems to measuring an individual's steps in a day. However, the ubiquity of computer use does not correspond with an increase in understanding of how these machines operate or their capability for solving new problems. The *creation* of computational artifacts is reserved for a few who possess the necessary skills of software and hardware development. This creates a power imbalance: a few create the programs, devices, and algorithms that will play a role in decisions that affect the masses. The ethical issues that emerge from this centralization of power are already evident in the cases of Facebook's polarizing timeline algorithms (Hern, 2017), parole decision algorithms (Angwin et al., 2016), and facial recognition artificial intelligence (Simonite, 2019).

Therefore, to better prepare our students for a computational world, researchers and educators propose integrating CT as a way to prepare children to engage with computational devices by going beyond just *using* them (Barr & Stephenson, 2009; diSessa, 2000; Grover, 2018). Instead, we aim to enable our children to think *with* computers (diSessa 2000)—to give them the learning experiences necessary to effectively use computers to address an undefined set of problems. By providing opportunities for students to solve diverse problems through CT, we expose them to the core concepts of computing and prepare them to become tomorrow's *creators* of technology.

But, before we can consistently provide those opportunities to engage in CT, we first need to understand how teachers learn to design and implement CT-integrated lessons and how they interpret and adopt the goals described above. As the educators responsible for facilitating CT opportunities in the classroom and supporting students' computing learning, understanding how best to prepare teachers and their own journey with CT is essential.

CT for Elementary School

Because computer science and computational learning have often been associated with college and high-school level learning, I explain the rationale that supports my focus on elementary school teachers. While, as explained above, researchers believe that all students should develop a computational literacy that will allow them to think *with* computers and not just use them, opportunities to develop this literacy have been disproportionately distributed among students. For example, Black students are less likely than their White counter parts to have computer science classes available in their K-12 schools, and girls are less likely to be aware of those opportunities (Google Inc. & Gallup Inc., 2016a). At the same time, girls are less likely to take a computer science AP exam, although the gender gap is beginning to narrow (Conti, 2018). At the college level, the gender and racial composition of graduates with computer science degrees resembles the inequalities in K-12 opportunities—although these trends are also improving (Myers, 2018). While these issues focus on the secondary and tertiary level, I argue that interventions aimed at improving diversity in computing should come earlier—when students are developing early career and vocational interests. One instance where children are faced with these decisions is by the first year of middle school (in the U.S.) At this point, many students are asked to choose to participate among different electives and afterschool programs. While a growing number of schools offer some type of CT or computer science learning experience, girls are less likely to be aware of those opportunities and less interested in learning computer science by middle school (Google Inc. & Gallup Inc., 2016a). Therefore, researchers argue that students should be exposed to computing early (Barr & Stephenson, 2011; Lu & Fletcher, 2009; Yongpradit, 2014), which considering the evidence cited above, should mean *before* students are asked to make choices on afterschool clubs and electives. In other words, students should be exposed to computing in elementary school. By aiming to spark and sustain interest in computing early, we seek to increase the interest and awareness of girls and students of color so that they become more likely to participate in computing throughout their academic careers. With this goal in mind, CT is a potentially productive tool to promote early interest and proficiency in computing among students from diverse backgrounds.

Proponents of this line of argument would typically support programs that provide developmentally appropriate CS experiences to children, such as block-based programming (e.g., Resnick et al., 2009), robotics construction kits (e.g., Sullivan & Heffernan, 2016), and tangible coding (e.g., Bers, 2010). These experiences are aimed at engaging children while teaching them the basic concepts of computer science like algorithmic thinking, conditionals, and debugging. But researchers' focus on engagement is not random—they are purposefully designed to "lower the floor" (Resnick & Silverman, 2005) of computer science and let all children feel excited and competent while creating with computational devices. In summary, the goal of integrating CT in K-12 settings is to prepare students for an increasingly computational world. The goal of focusing on the elementary level is to diversify the students that receive that preparation. Therefore, it is critical to understand how teachers interpret these goals and design lessons to meet it.

CT for Students by Teachers

As an educational reform, the push to integrate CT in K-12 focuses on student learning. Indeed, in the motivations I explained above, the goal is to engage *students* in CT to prepare them for a computational future. However, educational reforms—particularly those aimed at formal K-12 environments—depend heavily on teachers and how they implement the goals of the reform (Harn et al., 2013). Teachers are often tasked with translating learning standards, curricula, and policies into concrete learning activities for their students—all while navigating a complex set of school structures. One could argue that researchers and policymakers could "aid" this translation by focusing their investigation on student learning and creating resources that teachers can directly implement in their classrooms. However, this perspective underestimates the uniqueness of each classroom and its students and the difference in resource availability at each school. As we've seen with other reforms aimed at minimizing the flexibility of implementation, there are numerous issues with measuring and expecting "fidelity" in classroom implementation (Harn et al., 2013). Therefore, when it comes to educational reform, it is inevitably up to the teachers to make instructional decisions to comply with policy, work within the existing school structures and resources, and promote what they believe is meaningful learning for their students.

The reform to integrate CT into K-12 settings is no exception—teachers play a central role in how the type of learning expected from CT researchers and policymakers is enacted in their classrooms. In other words, teachers mediate the kinds of opportunities for CT learning that students engage in. Therefore, this study focuses on educators to understand how teachers plan those opportunities, how different teacher factors affect the types of opportunities they develop, and how these opportunities are ultimately delivered in their classrooms.

To contextualize this study and frame my research question and methodology, I review purposefully selected parts of the literature on CT below. The criteria behind each section is its relationship to this dissertation study. For instance, I start by summarizing the long—and largely unsuccessful—quest for a unique CT definition and explaining how that history affected research around CT because the blurry boundaries of CT affected how researchers in the PD experience presented content, planned activities, and assessed CT in participants. Then, I continue by examining how CT has been used in K-12 settings and presented to elementary school teachers, the relevant population for this study. I use a historical perspective to describe research on CT because the importance of this dissertation study is directly tied to the struggles of research in CT in the last few years. The historically blurry boundaries of CT, coupled with pressure to integrate it into K-12 contexts, creates a need for investigating how teachers—the *on the ground* drivers of educational innovation—appropriate CT to create learning opportunities that enact this new concept.

After revisiting the origin and trajectory of CT from a research proposition to K-12 settings, I review how the concept has been taught to teachers in recent years and point out specific limitations in existing research that motivate the need for this study. Finally, I summarize the theoretical perspective I adopted to organize the data collection and analysis strategies employed in this dissertation.

Defining Computational Thinking

The nature of computational thinking is contested terrain. Researchers, educators, and organizations have ventured into defining the term, creating activities to engage children in it, and measure its development. The multiple alleged origins and definitions of CT create—most sharply—a problem of implementation or operationalization**.** While some debates argue over the existence of CT, its core components, and who should learn it, the fuzzy boundaries of CT create most problems when working with particulars: developing learning experiences around CT for teachers and students. When educators and researchers create these experiences, even if we use a single CT definition or framework, we are still unsure on how to answer questions such as, What activities “count” as engaging students or teachers in

CT? Which behaviors or products count as evidence of CT development? Should children learn a CT skill in isolation to apply later or should they learn it in a disciplinary context? (Grover & Lee, 2019).

Yet, the issue of operationalization is central to this dissertation study. Even as researchers proposed different ways of creating concrete CT learning opportunities, teachers have had an additional operationalization task: from the PD experience and examples of researchers to their particular classroom within their county, their school, and for their students. However, it is important to understand how CT as a concept has evolved in the literature, particularly because this study, including the PD offered to participating teachers, builds on existing frameworks for defining and enacting CT in learning environments. The CT literature, with its ambiguities, still provides an empirical and theoretical ground to base this dissertation study while also revealing important topics in need of further research. Below, I review existing frameworks and research around CT to explain the concept's theoretical bases and highlight the limitations in extant literature that would be addressed by this study.

In 2006, Jeanette Wing, then the head of the Computer Science Department at Carnegie Mellon, published a short article where she laid her argument for Computational Thinking: "a fundamental skill for everyone, not just for computer scientists" (p. 33). In her article, Wing cast a broad net to define CT. The concept was defined a couple dozen times by describing different practices like "using abstraction and decomposition" (p. 33) and listing its characteristics, such as being "fundamental, not rote skill" (p. 35). Wing's argument focused around the power of computing to tackle large and complex problems—with CT being the key to unlock that power. However, while she made a compelling point to convince the research community on the importance of CT, the plethora of definitions in the article invited an even larger pool of interpretations. When Wing repeatedly "added" different components to her definition of CT, she—perhaps unknowingly—welcomed a blurry boundary of CT. As we'll see below, researchers took her list of CT components as separate pieces of CT, not interconnected parts that required each other.

Under that perspective, students did not need to engage in *all* parts of CT to access the value of CT—just a few of the mentioned parts of the definition should suffice.

Wing's article sparked a number of debates around CT, its importance for professionals outside of computer science, and explorations on its development in students (National Research Council, 2011). However, Wing's article is often considered a reintroduction of the term. The credit for defining CT is instead attributed to the work of early computing researchers (Tedre & Denning, 2016) and Papert in the 1980s, who investigated how children could learn mathematical concepts through interacting with computers and robots (Papert, 1980). Papert believed that computational environments, like LOGO, had the potential to develop new ways of thinking that could result in "new understandings of specific subject domains and new understandings of the process of learning itself" (p. 186).

Despite any debates over the origin of the term, CT quickly became a trendy subject in educational research after Wing's article, and the National Research Council (NRC, 2011) conducted a workshop inviting leading authors to share their perspectives on the "pedagogical aspect" of the debated concept. The report of the workshop was effective at pointing out the different interpretations of CT that existed in the field but highlighted the lack of common ground. For example, CT was defined by researchers in widely different manners: as a way of expression and fluently engaging in computing, as a way of breaking down problems to be solved by computational devices, and as a set of skills that can be applied to disciplines beyond computer science, among others. In fact, the lack of consensus in the definition was captured by one of the attendees: "I am left with two not-quite-consistent views of what computational thinking is and what everyone should be capable of" (p. 53).

So, when researchers needed a narrower CT definition that could create convergence and collaboration, attempts to re-define CT fell short—CT was still ill defined as a long list of practices and dispositions that could be found virtually anywhere. For example, Wing (2011) wrote another article where she defended her broad definition of CT and explained some of its possible applications for disciplines beyond computer science and daily life. At the same time, Barr and Stephenson (2011) proposed a vision of CT specifically for K-12 contexts that emerged from collaborating with educators and computer scientists. In their view, integrating CT in the classroom would require systemic changes involving classroom dynamics, teacher and student use of computational language, and numerous age-appropriate examples of CT for teachers to use as resources. However, the examples that the authors provided for disciplines beyond computer science and math often lost the “centrality of the computer” (p. 51) that they advocated as the unique characteristic of CT. For instance, they provided “summarize[ing] facts; deduc[ing] conclusions from facts” as examples of CT in Social studies and “Do[ing] and re-enactment from a story” as CT in Language Arts. These examples, like Wing’s original article, invited a broad application of CT with blurry boundaries. At the same time, the Computer Science Teachers Association (CSTA) and the International Society for Technology in Education (ISTE) created a joint report (2011) with an “operational definition” of CT that included “dispositions” like dealing with frustration and complexity as parts of CT. While this definition broadened CT to conceptualize it as more than just a set of practices or skills, it may have contributed to CT’s already indistinct boundaries.

Recognizing that the multiplicity of CT definitions was obstructing a clear research agenda for CT, Grover and Pea (2013) reviewed the extant literature to synthesize a common set of factors that CT definitions had in common. They concluded that CT has a set of “widely accepted”(p. 39) components:

- Abstractions and pattern generalizations (including models and simulations)
- Systematic processing of information
- Symbol systems and representations
- Algorithmic notions of flow of control
- Structured problem decomposition (modularizing)

- Iterative, recursive, and parallel thinking
- Conditional logic
- Efficiency and performance constraints
- Debugging and systematic error detection

Grover and Pea’s article was valuable in synthesizing the literature around CT and its definition, and it catapulted the field into tackling the next logical issue in CT’s historical timeline: operationalizing the abstract components of CT for particular learning contexts. This study is amidst the ongoing debate around CT, as it investigates a PD program that designed its own framework for CT integration into elementary science instruction (Ketelhut et al., 2019). This framework is meant to help teachers conceptualize and operationalize CT for the specific context of science education at the elementary level (a detailed explanation of the framework is in Chapter 3).

As mentioned in the beginning of this section, the issue of operationalization is key to this dissertation study. Teachers, once they have learned about CT through one or more of the frameworks discussed above, still need to materialize that learning onto lesson plans or units. As I review below, even when researchers worked directly with students and teachers to operationalize CT for K-12 contexts, the structures of classrooms and schools—which teachers necessarily have to work within—affects how CT is implemented in the classroom. This study aims to further illuminate the relationships between CT operationalizations, PD designers or researchers, teachers, and classrooms.

CT in K-12

Next, I turn to trends in mapping the abstract definitions of CT reviewed above to concrete applications in K-12 classrooms and learning environments. I review two trends as they both relate to how CT was operationalized by PD researchers when addressing the participating teachers in this dissertation study. As researchers began to take CT to educational contexts, two main ways of "translating" CT's abstract definitions to K-12 activities for students emerged: (1) integrating authentic computing activities—e.g., programming—that engage children in CT and (2) leveraging the power of CT to transform how students engaged with disciplinary content, which resembles how computing has permeated into fields other than computer science, such as computational biology or history.

CT as Problem-Solving in Computer Science

On one hand, numerous educators and researchers operationalized CT by sticking close to its computer science origins, using developmentally appropriate programming or coding as the default activities that embody CT. One literature review suggests that CT's most common operationalization is, in fact, programming activities (Hsu et al., 2018). For example, Brennan and Resnick (2012) analyzed how three children programmed different games in Scratch—an educational programming environment designed for children (Resnick et al., 2009). In their analysis of the children's game designs, they defined CT as "a device for conceptualizing the learning and development that take place with Scratch" (p. 2). The authors kept a tight link between CT and creating computational artifacts, an activity they argued included understanding computational concepts, enacting computational practices, and developing computational perspectives. Other researchers have also considered programming activities as the "default" instance of engagement in CT. For instance, scholars have investigated how students develop CT skills by debugging algorithms (e.g., Liu et al., 2017), creating or designing digital games (e.g., Jenson & Droumeva, 2016; Weintrop, Holbert, et al., 2016), and programming robots (e.g., Angeli & Makridou, 2018; Caitlin & Woollard, 2016).

Some authors also contend that CT can be operationalized within a computing context but *without* physical computing—an "unplugged" approach. These researchers argue that the problem-solving strategies of CT can be applied to a problem without requiring a computational agent to execute them. For instance, Berland and Lee (2011) explored how board games—which are unplugged environments—can serve as settings for the development of CT. The authors describe how CT can emerge “spontaneously” (p. 67) during play and contend that the type of thinking students engage in while playing could be “leveraged for instruction” in the future. Other researchers explored the use of unplugged CT strategies in formal environments. For example, Faber, et al. (2017) engaged students in CT activities including writing “code” to win pen-and-paper games, determining different outcomes depending on the value of a card being drawn, and sorting classmates or animals based on predetermined criteria. The authors argue that each of their six activities taught a different fundamental concept of computing, and one could argue that the implicit assumption is that these foundational understandings could be beneficial for students in the future. However, this assertion has not been empirically tested: the effects of CT learning experiences on subsequent interest or proficiency in computing are under-investigated.

When *assessing* the development of CT, multiple researchers also used programming activities as a context to evaluate CT skills. For instance, Rose, Habgood, and Jay (2017) aimed to understand the role of visual interfaces in the development of CT for young children by comparing how students performed using two developmentally appropriate programming environments. Even if the programming activity was unplugged, it was made to resemble the process of programming in a computational environment. For example, Tran (2018) investigated how third graders developed CT skills by participating in a multi-week coding intervention. The students used programming environments designed for elementary school children and performed significantly better in the post-test. In this study, the assessment of CT, completed on pen-and-paper, consisted of ordering the steps of an algorithm, completing a puzzle by writing down discrete instructions, grouping different steps into loops, and determining the outcomes of conditional statements. In these assessments, students were required to show their CT proficiency within a programming context (plugged or unplugged), which demonstrates the implicit assumption that programming is at least one main medium where CT is of critical importance.

As a group, the literature around efforts to operationalize CT as a problem-solving strategy closely tied to computing shows that students can learn the basics of computing and engage in CT by directly interacting with computational environments. Moreover, the rationale for maintaining CT's operationalizations close to the core of computer science supports some of the goals of the CT movement. If the reform is intended to prepare students—particularly girls and students of color—to engage in computing, then CT *should* be directly tied to authentic computing activities where CT is necessary to solve problems—such as programming environments. However, limiting CT's operationalizations to programming or computing-related activities also has some limitations. For instance, this approach can underestimate the difficulty of bringing authentic computing activities into the classroom. Introducing CT *through programming activities* would require a high level of computer science knowledge from teachers, who are typically not trained in computing. In fact, principals claim that the most prevalent reason for lack of computing opportunities in their schools is the unavailability of trained teachers (Google Inc. & Gallup Inc., 2016b, Appendix B). At the same time, these types of operationalizations would require appropriate technology, which can create inequity issues for those schools or districts who do not have the resources to buy devices. Additionally, introducing computing activities to engage children in CT requires curricular flexibility: teachers would need "extra" time to spend on a topic that is not directly tied to the way students, and teachers, are evaluated. This burden could prove too heavy and limit the feasibility of integrating computing activities in the classroom.

For these reasons, CT in this study is conceptualized as going beyond its computer science origins. While it is clear that CT and programming are deeply connected, the PD experience that teachers participated in presented CT as a problem-solving strategy that can be valuable outside of programming environments. Instead, we posed CT as a set of practices that can be integrated into science instruction to transform how students engage with scientific content (Ketelhut et al., 2019).

CT to Transform Engagement with Disciplinary Content

Because this study is focused on how CT is integrated into science teaching, I review the literature on CT as a way to engage children with scientific content maintaining a historical perspective. Responding to the need for new content to work within existing school structures, a different line of research conceptualizes CT not as a learning goal itself but as a *method* for transforming how students engage with disciplinary content. In the words of diSessa (2018), this research agenda promotes a computational literacy where disciplinary content is “re-mediated” through computing (p. 8). Under this conceptualization of CT, students engage with disciplinary content through computing activities such as exploring computational simulations, creating algorithms to describe or design processes, or analyzing large quantities of data in computational environments. In this way, diSessa argues, the content is *mediated* by computing—a process that significantly affects *how* students learn disciplinary content, not just *what* they learn.

This conceptualization of CT emerged as the impetus to integrate CT into formal classrooms clashed with the constraints of limited instructional time and curriculum inflexibility. Under these circumstances, researchers began exploring other ways of exposing students to computational experiences. Education researchers, recognizing the increasingly computational nature of professional science, proposed an integration of CT into science, which would require changing how curriculum was taught—not adding to it (Cateté et al., 2018; Sanford & Naidu, 2016; Sengupta et al., 2013; Weintrop, Beheshti, et al., 2016). In other words, researchers were looking to integrate CT into science instruction while acknowledging that teachers are held to specific disciplinary standards, and that educational innovations that do not support learning towards those standards will be difficult to implement.

Within these requirements, researchers and educators highlight two main potential benefits of integrating CT in science. On one hand, involving students in engaging computational activities with animation, robots, and programming can spark—and maintain—an interest in STEM, which begins to decline in middle school, particularly for girls (Google Inc. & Gallup Inc., 2016a). On the other, exploring scientific phenomena with computational approaches could lead to more meaningful and deeper learning experiences by allowing students to engage with content in a completely different way (Berland & Wilensky, 2015; diSessa, 2018). For example, Berland and Wilensky (2015) demonstrated how two groups of students who investigated complex systems in a biology class developed different types of perspectives or understandings on those systems depending on the environment they used to learn. Those using a physical environment where robots (“agents” within the complex system) moved developed a “bottom-up” understanding of each system. In contrast, those who programmed virtual robots in a virtual environment, developed an “aggregate” or “top-down” perspective of how each system works. The researchers did not evaluate whether one perspective was better than the other—their main point is that the type of computing experience can play a role in the type of understanding students develop.

Researchers have also investigated the potential of CT to investigate complex scientific systems. For instance, Blikstein and Wilensky (2009) conducted a study with college students where they explored the atomic behavior of materials by interacting with computational models. The authors showed how engaging with this complex disciplinary topic through computational simulations “foregrounded the fundamental physical processes in the material” (p. 25) and made conceptual understanding more easily accessible than the typical approach of equation and variable “overloading” (p. 2). Using a similar tool involving virtual agents, Sengupta, Kinnebrew, Basu, Biswas, and Clark (2013) found that middle school students who interacted with the computational simulation were able to “represent and interpret motion as a process of continuous change in position and speed” (p. 374) as measured in their assessment.

Other research has also demonstrated the value of approaching scientific issues through computational methods—even without new or custom technology. For instance, Matsumoto and Cao

(2017) described how high school students managed data related to chemical reactions and compositions by using Excel—a tool readily available in most U.S. high schools. The authors demonstrated how students conceptually engaged with different chemical processes by creating computational models to represent them.

However, these studies have normally been led by researchers who either participate in the teaching of scientific content through CT or are heavily involved in the planning of educational activities. At the same time, many of these applications require computational devices, and many employed customized software developed for each study (such as NetLogo simulations for complex systems). Therefore, research in CT as a way to engage with scientific content retains some of the limitations of approaching CT as a problem-solving strategy in computer science. While this strategy allows teachers and schools to integrate CT without having to find additional instructional time, the demanding requirement of educators' proficiency in computing can prove a significant barrier to scaling integration efforts (Mouza et al., 2017), especially when teachers have limited experience with computer science (Yadav & Berges, 2019). Below, I summarize these emerging barriers by reviewing recent research around teacher preparing to integrate CT into their instruction.

CT in Teacher Education

As researchers investigated the value of integrating CT—whether through developmentally appropriate computer science activities or integrated into other disciplines—a new need also became apparent: teacher preparation. As Barr and Stephenson (2011) had anticipated, integrating CT into formal environments would require a grand effort to "inspire and prepare" teachers (p. 53).

Research on teacher education around CT is diversified among different countries, grades, disciplines, teacher populations (e.g., pre-service and in-service), and approaches to CT learning and integration. Some researchers seek to understand how pre-service teachers can learn about CT in their university courses and develop their own curricular materials to implement them in the future. These studies focus on understanding how teacher educators can employ different strategies to support student-teachers in learning about the nature of CT and how to create CT learning opportunities for their students. One common way to approach pre-service teacher learning around CT is to integrate it into existing university courses. For example, Mouza et al. (2017) designed an educational technology course that prepared students to integrate CT into K-8 settings. Pre-service teachers learned about the practices that encompass CT, technologies that can foster its development, and how CT can be integrated into classroom activities. The authors present conservative results: some teachers showed "surface understanding" and struggled to create lessons that authentically integrated CT practices. Also integrating CT in a pre-service course, Yadav et al. (2014) introduced teachers to the definitions and practices of CT and later examined their level of comfort with computing and their definitional knowledge of CT through multiple-choice assessments. The authors find that teachers felt more confident about their understanding of CT and were less likely to select answers that represented common misconceptions about CT, such as defining it as "thinking like a computer" (p. 7). Other researchers have also explored how pre-service teachers develop an understanding of CT by designing games (Lamprou & Repenning, 2018), designing CT-infused science lessons (McGinnis et al., 2019), exploring scientific computer models (Adler & Kim, 2018), and programming in Scratch or other digital environments (Cetin, 2016; Gadanidis et al., 2017; Sadik et al., 2017).

Other work focuses on *in-service* teachers and seeks to leverage the existing professional knowledge of experienced educators to create new integration opportunities that infuse CT into the curriculum. A common approach within this line of research is to integrate CT within existing classroom curriculum, typically in disciplines where computational approaches can help students engage with content. For instance, researchers have designed PD experiences to prepare teachers to integrate CT into science instruction (Ahamed et al., 2010; Cadieux Boulden et al., 2018; Hestness, Ketelhut, McGinnis, & Plane, 2018). However, even in-service teachers have issues translating their newly acquired CT knowledge to their educational contexts. For instance, Israel, Pearson, Tapia, Wherfel, and Reese (2015) investigated how teachers and administrators within an entire school integrated CT and reported wide variability in CT implementation. Moreover, teachers faced multiple obstacles when attempting to integrate CT into their instruction, such as requiring extra time to get acquainted with new technologies.

As a group, research aimed at integrating CT into teacher education—whether pre- or in-service—shows that participants can develop a higher sense of comfort around CT, its concepts, and its pedagogical applications. However, these studies are typically limited to university classroom or PD contexts, where teachers *learn* about CT but do not have an opportunity to *practice* its integration. Additionally, both pre- and in-service teachers recognize that implementing CT lessons (as opposed to just designing them) could involve expected and unexpected obstacles that affect those implementations. The available exceptions, where researchers *see* into the classroom, have a few limitations. For instance, Israel et al. (2015) investigated how teachers implemented CT lessons, but were only able to do so in one school context. The authors contend that further research should focus on multiple schools to understand which aspects of CT vary—and which remain constant—across different educational settings.

On the other hand, Rich and Yadav (2019), while researching multiple teachers within different schools, focused on unplugged applications of CT. Given the limitations of these approaches explained above, and the intricate relationship between CT and technology, such accounts may only depict a limited portion of the impact of CT PD on teachers' instruction. Therefore, the existing research around teacher education for CT leaves unanswered questions about how CT plays out in the classroom after teachers graduate from their programs or complete their participation in PD experiences. This dissertation aims to shed light on that process by adopting a theoretical framework of teacher appropriation of pedagogical tools, which I proceed to contextualize and describe below.

From Teacher Education to Classroom Implementation

The issue of teachers implementing newly acquired instructional practices is not new to the field of education. Although limited examinations of teachers implementing CT practices in their classroom after instruction exist, theories around how teachers learn and integrate other instructional techniques into their teaching can be informative for this study. Specifically, literature around the links between PD and implementation, as well as the factors that affect how teachers apply new knowledge in their classrooms, can serve as an initial guide for elements that could be relevant in *this* study of learning and implementation.

Theories around how teachers implement pedagogical innovations or adopt instructional change are varied and propose a plethora of potentially influential factors. However, two main types of factors emerge from the literature: (1) teacher beliefs, knowledge, or characteristics and (2) external factors such as administrative or curricular support. For instance, in an early review of how teachers react to systemwide changes, Waugh and Punch (1987) highlight different kinds of teacher beliefs that affect how they receive the proposed changes. Specifically, they identify beliefs around the practicality and difficulty of the innovation, and external support as general variables that can impact how teachers react to systemwide change.

Moreover, other frameworks explaining factors that contribute to teacher change also emphasize the role of beliefs and context in describing how teachers adopt new strategies or knowledge. For example, Gregoire (2003) described the Cognitive-Affective Model of Conceptual Change (CAMCC) as a process where teacher beliefs (specifically whether the proposed innovation implicated her and whether she had sufficient motivation and ability to carry the innovation forward) ultimately decided whether the teacher would result in true conceptual change, no conceptual change, or merely superficial change. This model of teacher change presented beliefs around efficacy (internal) and ability (including external factors like time and resources) as central to a teacher's ultimate level of change.

However, this linear conceptualization of teacher change has been critiqued by other scholars. Clarke and Hollingsworth (2002) critique models of teacher change for oversimplifying change as a linear process and instead suggest that teachers change through reflecting and enacting across four different domains that include aspects related to both beliefs and context as explanatory influences on teachers' change.

Although these models of teacher change could potentially be helpful to investigate how teachers change to integrate CT in their classrooms, they would pose a significant limitation as theoretical frameworks for this study: their focus is too general to explain how *specific* aspects of a pedagogical innovation or PD experience can make their way into the classroom. While they may be helpful to explain *which* factors are important in general processes of teacher change, they may be less effective in determining *how* those factors are impactful in how teachers implement a *specific* pedagogical innovation.

On the other hand, a more fitting framework for this study focuses on how teachers adopt a particular innovation and describes the different levels in which teachers can integrate a new pedagogical tool into their teaching repertoire. The framework of teacher appropriation (Grossman et al., 1999) poses that teachers can reach five different levels of appropriation when adopting a new pedagogical tool—in this case, CT for science teaching.

The authors describe appropriation as "the process through which a person adopts the pedagogical and conceptual tools available for use in particular social environments (e.g., schools, pre-service programs) and through this process internalizes ways of thinking endemic to specific cultural practices" (p. 15). Based on Activity Theory (Cole, 1996), this framework posits that teachers can appropriate new pedagogical tools, such as instructional practices or conceptual tools, in a continuum with five distinct levels:

1. Lack of appropriation. Teachers do not appropriate the instructional practices, which could be for multiple reasons. This does not mean they do not understand the pedagogical tool—they may be unable to adopt it for external reasons.
2. Appropriating a label. Teachers appropriate just the language around a pedagogical tool and may know some of its features but do not fully understand the concepts behind those terms.
3. Appropriating surface features. Teachers appropriate some of the features of the pedagogical tool but may still not fully understand the larger "conceptual underpinnings" behind those features. For example, they may adopt some instructional practices while making some modifications that erode the motivation or conceptual support behind those practices. The teachers would still believe that they are implementing the pedagogical tool fully.
4. Appropriating conceptual underpinnings. Teachers appropriate the concepts that support the pedagogical tool and may be able to apply them in new instructional situations. However, a teacher may appropriate conceptual underpinnings without understanding practical applications of those concepts or being unable to test them out in her classroom.
5. Achieving mastery. Teachers are able to use the pedagogical tool effectively and understand its conceptual underpinnings. The authors suggest that likely, achieving mastery requires years of practice and experience with the pedagogical tool.

These levels of appropriation demonstrate a continuum of conceptual understanding and application of the innovation. At lower levels, the teacher does not appropriate the pedagogical tool or shows little understanding of it. At higher levels, she can adapt the tool effectively for her classroom and fully understands its conceptual underpinnings.

At the same time, Grossman and colleagues describe factors that impact the level of appropriation teachers achieve, which resonate with the literature of implementation reviewed above. Specifically, the authors highlight the *social context of the learning* and *characteristics of the teacher* as ultimately impacting how teachers appropriate the pedagogical tool. Therefore, the framework of appropriation acknowledges the major factors that have been identified as influential in teacher change while also providing a conceptual guide to determining how a *specific* innovation is adopted by teachers in different levels (Figure 1).

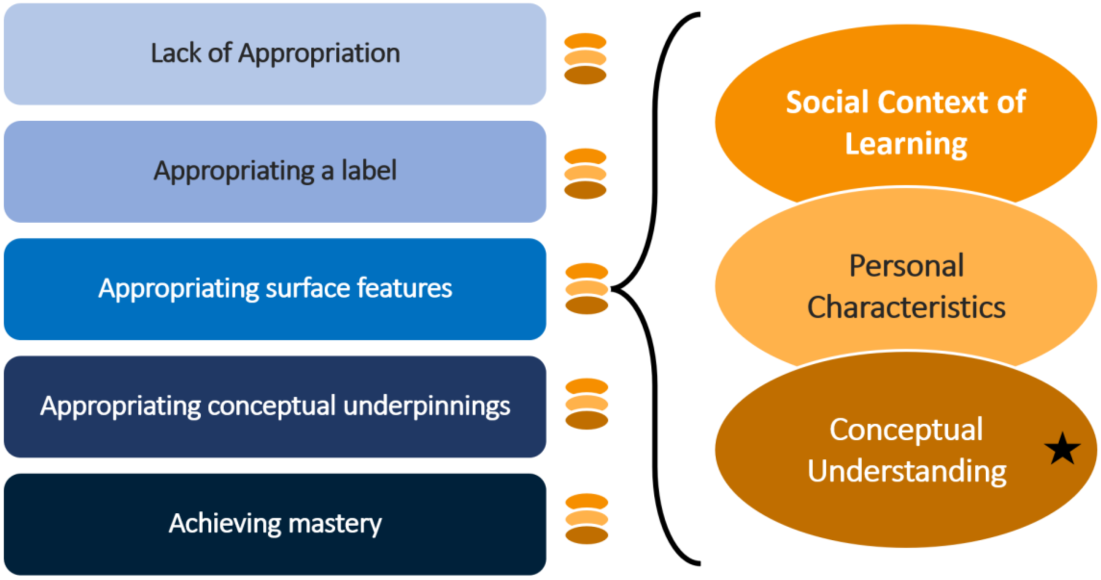


Figure 1. Grossman et al.'s (1999) framework of appropriation of pedagogical tools. A teacher's appropriation level is determined by three factors—conceptual understanding being a key difference between each level.

Grossman et al.'s (1999) framework of appropriation has recently been used to investigate how teachers adopt new technologies and pedagogical strategies into their teaching. For example, Longhurst, Jones, and Campbell (2017) conducted a study to understand teachers participating in a PD experience appropriated technology differently in their classrooms. Using Grossman et al.'s (1999) framework, the authors analyzed how practical and conceptual tool dispositions were associated with different levels of appropriation. They concluded that, to support higher levels of appropriation, PD should provide opportunities for teachers to adapt the tool to their needs, establish a “trusted community” (p. 378) where teachers and researchers work together, and make explicit connections between PD learning and benefits that these pedagogical innovations could bring to students.

Similarly, the framework has been used to investigate teachers’ appropriation of pedagogical tools for communicative language teaching (Reynolds, 2012), reading instruction (Leko & Brownell, 2011), and teaching issues of social justice (Henning, 2013), among others. Therefore, Grossman et al.’s (1999) framework, then, can be a potentially productive tool to investigate about how teachers adopt CT—a conceptual pedagogical tool—to integrate it into their science teaching.

This dissertation builds on applications of the framework to understand the process of teacher learning and appropriation of a pedagogical tool. It specifically addresses the gap in knowledge around how teachers appropriate CT for their classroom through PD and how appropriation evolves after their participation. It also contributes to our understanding of the process of teacher learning by providing a detailed description of the roles that different factors (conceptual understanding, social context, and personal characteristics) play in the appropriation of CT as a pedagogical innovation.

Chapter 3: Methodology

This study is divided into two parts, each led by a different research question (Table 1). The first part of this study constitutes a secondary analysis of existing data from a Design-Based Research study (described below). As such, it is best described as an observational case study, where the main data-gathering technique is observing participants and collecting artifacts they create (Bogdan & Biklen, 2007). The context for the study is the Science Teaching Inquiry Group in Computational Thinking (STIG^{CT}) professional development series (described in the next section).

Table 1. Research study organization

Research Questions	**Methodology**	**Data Sources**	**Data Analysis**
How do teachers participating in a CT-focused PD experience appropriate CT to integrate it into their science teaching?	Observational case study. The case is the STIG^{CT} and the focus is teachers' appropriation of CT during the PD.	Self-efficacy surveys, assessments of CT conceptualizations, PD participation reflections, PD researcher field notes, lesson designs, participant interviews, and classroom observations.	Deductive analysis of data using the three factors that impact appropriation (conceptual understanding, personal characteristics, and social context) as categories.
How do different types of CT appropriation correspond to teachers' reflections of their CT integration within their classrooms?	Holistic multi-case study with teachers selected for theoretical replication. The focus is on teachers' integration of CT.	Data sources from the STIG^{CT} listed above plus interviews a year after the conclusion of the PD. The interviews capture how teachers reflect on their integration of CT throughout the academic year that followed the STIG^{CT}.	Inductive analysis of teachers' reflections. I specifically analyzed how emergent themes impacted the processes of planning and implementing CT-integrated science lessons.

The study investigates how STIG^{CT} participants appropriated CT as a pedagogical tool for their science instruction. In this first part of the dissertation, the analysis is done at the group level and conceptualized as an observational case study (Bogdan & Biklen, 2007), with the STIG^{CT} being the case and teachers' appropriation of CT the subject. I aim to find patterns of CT appropriation that emerged among the participants of the STIG^{CT} and illuminate the common factors that led to that appropriation style. Data for this phase was be drawn from multiple sources including self-efficacy surveys, assessments of CT conceptualizations, PD participation reflections, PD researcher field notes, lesson designs, participant interviews, and classroom observations. Except for the surveys, which could be analyzed quantitatively, all other data sources are qualitative.

The second part of this dissertation is designed as a holistic multi-case study (Yin, 1994) where cases are selected for "theoretical replication" (p. 46). For this study, each participant represents a case of integration, as each teacher is responsible for designing, implementing, and reflecting on her own lessons, and would therefore constitute a unique case of integration. The study is also considered *holistic* because the cases are compared to each other and discussed as examples of the larger phenomenon of appropriation after STIG^{CT} participation. To answer RQ2, I conceptualize CT integration as involving three distinct processes: the design of, implementation of, and reflection on CT-infused science lessons. For each case, my analysis aims to illuminate how the experiences of teachers in the STIGCT and the year after participation impacted those processes. Data for this phase is drawn from interviews as well as the data sources listed above.

Additionally, the selection of cases (teachers) focuses on theoretical replication, meaning that each case is expected to produce "contrasting results for predictable reasons" (Yin, 1994, p. 46). The main reason to expect variability in integration lies in the differences in appropriation levels of CT (Grossman et al., 1999). As teachers appropriate CT with varying styles and degrees of sophistication, it is likely that the process of integration they execute changes accordingly.

However, there are additional reasons to expect different results from each teacher at a theoretical level. The teachers who volunteered to participate in the second phase of the study taught in different schools, different grades, and displayed different appropriation styles during the STIG^{CT}. These differences were likely to create varied ways of integrating CT into elementary science, providing multiple cases for theoretical replication.

Context

This dissertation study leverages the context of an existing PD program to understand how teachers appropriate CT during and after their participation. Below, I describe the PD program, its participants, and the research procedures that took place during the PD.

STEM+C Grant

This dissertation study focuses on the PD intervention portion of a project titled Exploring the Integration of Computational Thinking into Preservice Elementary Science Teacher Education (CT→PSTE), funded by the National Science Foundation (NSF) through the STEM+C grant solicitation. The CT→PSTE research team (which has evolved over the years of the grant) involved multiple doctoral students, post-doctoral researchers, and three Co-Principal Investigators. Because different team members had different areas of expertise (e.g., science education, computer science, teacher education), all aspects of the grant were designed in a collaborative way. At the time of writing this dissertation, my participation has been as a Graduate Assistant for over four years. Specifically, I have worked on designing and implementing our interventions (described below), designing data collection protocols, facilitating PD sessions, collecting and analyzing data, and writing reports on our findings. Throughout the rest of this document, I refer to the CT→PSTE research team as "we" and differentiate when I discuss ideas that are pertinent *only* to this dissertation by using "I" as a pronoun.

The CT→PSTE study was a Design-Based Research (DBR; Brown, 1992; Collins, 1992; Collins, Joseph, & Bielaczyc, 2004) investigation where we provided two main ways of intervening in teacher education to integrate CT into science teaching: a CT integration module in a science methods course, and the STIG^{CT}—a professional development series.

First, we created a CT module to be included in our university's Science Methods Course, and we refined the design of that module through three iterations to respond to how our preservice teachers—whom we refer to as *residents*—developed understandings of CT and reflected on their educational experience. The modules were implemented in three sections of the course and involved a presentation of the adapted CT framework (explained below), an activity where residents programmed robots to complete a set of challenges, and an exploration into unplugged CT activities. Instructors also facilitated discussions around the nature of CT, how to integrate its practices into science lessons, and the value of integration for K-5 students. Residents also were tasked with designing lesson plans that integrated CT, to try them—if possible—in their classrooms, and to reflect upon those experiences.

Second, we conducted a series of PD sessions in the semester following the course module where a subset of residents and their mentors—in-service teachers—participated together to learn about CT. We also invited other experienced teachers, who were not mentors to a course resident, to participate through the University's Professional Development Schools coordinators. A total of 38 teachers began the program, and 35 completed it. Participants taught in different grades and came from different counties as detailed in Table 2.

Table 2. Participant characteristics.

	Pre-service		In-service		Full sample	
	n	%	n	%	n	%
Gender						
Women	19	95	15	100	34	97
Men	1	5	0	0	1	3
Grade						
1st	4	20	1	7	5	14

2nd	1	5	1	7	2	6
3rd	7	35	4	27	11	31
4th	6	30	7	47	13	37
5th	2	10	2	13	4	11
County						
A	16	80	11	73	27	77
B	4	20	2	13	6	17
C	0	0	1	7	1	3
D	0	0	1	7	1	3
Race						
Asian	3	15	0	0	3	8
Black	2	10	0	0	2	6
Latino/a	3	15	1	7	4	11
White	12	60	15	100	27	77
Age						
18-25	19	95	1	7	20	57
26-35	1	5	5	33	6	17
36-45	0	0	6	40	6	17
46+	0	0	3	20	3	9

Note: Percentages may not add up to 100 due to rounding. Participants could select more than one race.

This afterschool experience was called the Science Teaching Inquiry Group in Computational Thinking (STIG^{CT}), as it was designed to create a community of inquiry (Garrison et al., 1999; Lipman, 2003) of residents, mentors, experienced teachers, participants from previous STIG^{CT} implementations, and researchers from different academic backgrounds to design ways to integrate CT into elementary science collaboratively. Before the beginning of the STIG^{CT}, all in-service teachers participated in a 3-hour workshop which encompassed an abbreviated version of the CT module that residents had experienced. The goal of this workshop was to ensure that all STIG^{CT} participants would have the same level of CT exposure at the beginning of the program. The design of the STIG^{CT} sessions also underwent major revisions after each year of implementation and, in its final year, adopted a format of four monthly 3-hour sessions throughout a semester. Because the participants for this study were recruited exclusively from the participant pool of the last implementation of the STIG^{CT}, I describe the structure of the final PD design in more detail than the CT module of the Science Methods Course above.

The final design of the STIG^{CT} involved four sessions with different foci but a similar structure. Each meeting, we started with a discussion of the day's CT practice, then proceeded to have teachers participate in one or more activities that modeled a CT-infused science lesson, discussed how CT was embedded into those learning experiences, and provided time for teachers and researchers to co-design lesson seeds—short drafts of science lessons that integrated CT. Participants were also required to, at least one time in the semester, develop a full science lesson plan that integrated CT, implement it in their own classrooms (without any researcher observation), and reflect upon it. In the final STIG^{CT} session, participants shared their lesson plans and reflections on implementations of those plans with peers and researchers.

To structure our conversations around CT in both intervention aspects, the research team provided a CT framework (Figure 2), which borrows heavily from Weintrop et al.'s work (2016) and presents CT as four groups of practices: Data Practices, Programming, Simulation, and Systems Thinking. Each group has specific practices, as seen in Fig 1. Participants received paper copies of the framework, which was referenced often during the sessions to highlight different practices in display, comment on potential integration opportunities, and nuance the definitions of each practice according to the researchers' CT perspective. When we presented activities and practices, we made sure to stress how engaging in these CT practices would expand the way that students engaged with scientific content or could prepare children to pursue an interest in computing. The final framework used in the 2019 STIG^{CT} is the result of multiple iterations that responded to participants' understanding and feedback during previous implementations (Ketelhut et al., 2019).

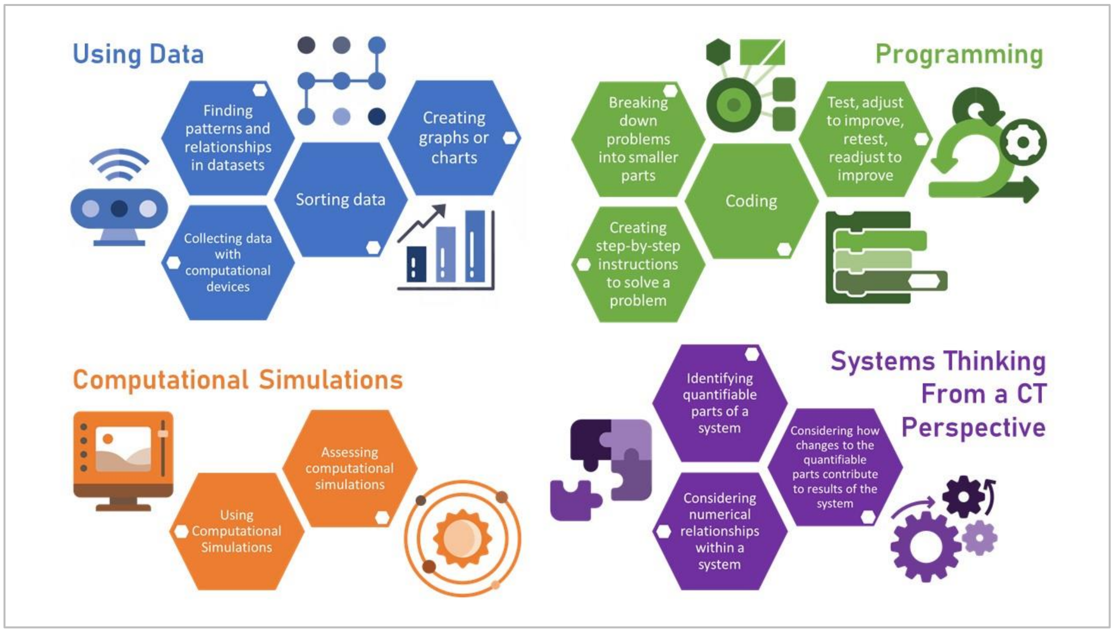


Figure 2. CT Framework presented to STIG^{CT} participants.

Participant Recruitment

All participants for this dissertation study were recruited from a pool of teachers who participated in the STIG^{CT} within the CT→PSTE study and showed an initial interest to participate in this study when approached in May 2019. After a year of the last STIG^{CT} session had passed, I contacted teachers to ask whether they would be interested in participating in a set of three remote interviews to understand how they integrated CT in the last academic year. While an original research plan included classroom observations of teachers implementing CT-integrated science lessons, the procedures were revised to comply with new research restrictions during the COVID-19 pandemic. A total of five teachers volunteered to participate in the remote interviews. They received a stipend ($150) for completing all three interviews.

Teachers were not selected purposefully for this study, any teacher who wanted to participate and met the criteria could do so. However, the teachers who volunteered to participate represented diversity in their schools, levels of appropriation, and grade they taught. This allowed for analyses that highlighted contrasting instances of integration and produced theoretical replications (Yin, 1994, p.46).

Procedures

As mentioned earlier, participants in this study were teachers who had participated in at least six months of professional development around CT—the STIG^{CT}. To contextualize the data collection process, I describe—chronologically—how teachers participated in the STIG^{CT} and how they continued to participate in this study (see Figure 3). Then, I detail each instrument that was used during the STIG^{CT} data collection period and those employed in the rest of the study. The dissertation involved a secondary analysis of existing data from participants STIG^{CT} experience, a new data collection phase focused on classroom implementation, and a final analysis of *all* data collected.

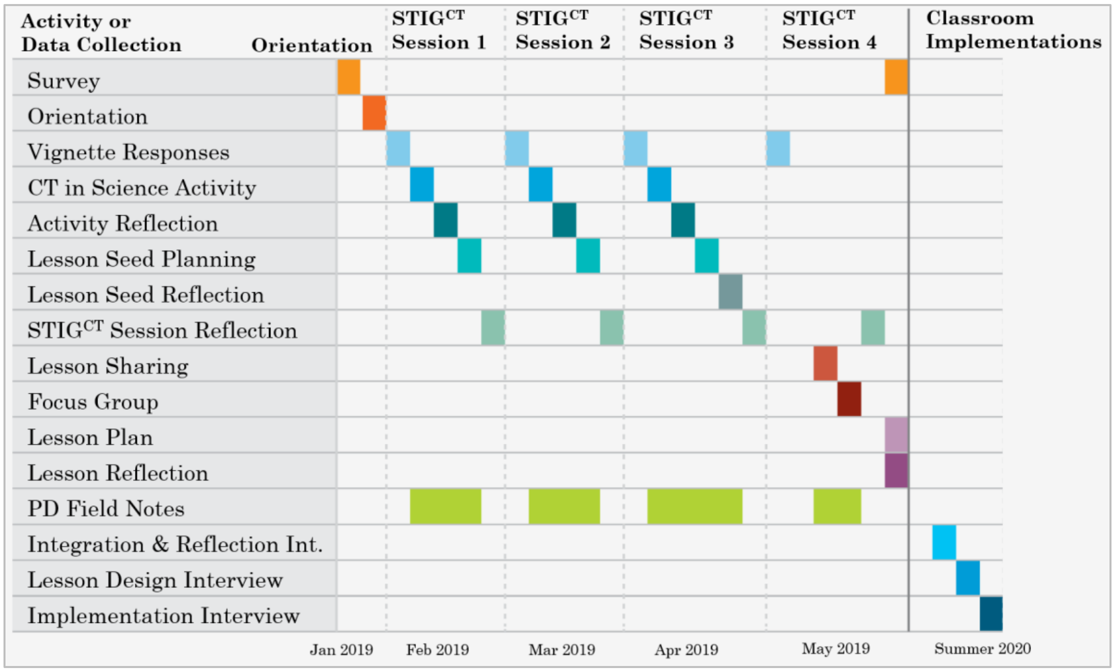


Figure 3. Timeline of data collection.

Data Collection: STIG^{CT} Instrumentation

In this section, I describe each data collection method and its associated instrument(s). I begin by describing all the methods used in the STIG^{CT} sessions and then describe the interview and observation protocols that will be used in the rest of the study.

Surveys

In two occasions—at the beginning and end of the STIG^{CT} experience—participants completed a survey that aimed at measuring (a) their self-efficacy in integrating CT into their science teaching, (b) their judgment on the importance of CT for science education, and (c) their perceived level of support to integrate CT from different factors including their school's administration and the county's curriculum. The final instrument is the second iteration of the survey and it showed strong internal reliability in each factor (Cabrera, Byrne, Ketelhut, in preparation). The complete instrument is found in Appendix A. The first factor, self-efficacy around integrating CT into science teaching, was measured through 8 items that described different activities a teacher may do to integrate CT into science teaching—like defining CT and adapting lessons to include it. To respond to these questions, teachers marked their ability to complete each task on a scale from 0 (*definitely cannot do it*) to 100 (*definitely can do it*). The design of this self-efficacy subscale was in line with Bandura's recommendations for creating self-efficacy scales (2006) and recent developments in survey methodology (Krosnick & Presser, 2010).

The second and third factors of the survey were measured by asking respondents to indicate their level of agreement on a six-point Likert type scale. The surveys are designed to capture teachers' attitudes regarding multiple aspects of CT and its relationship to science teaching.

Vignette Responses

The vignettes are a set of instruments designed to assess teachers' conceptualizations of CT based on the work of Yadav, Krist, Good, and Nadire Caeli (2018). Each vignette is a separate hypothetical scenario of a teacher implementing a classroom lesson. Participants responded to each vignette by determining whether children engaged in CT in the given scenario by choosing either *yes*, *no*, or *maybe*. If respondents chose that children did not engage in CT in the vignette, they were given space to expand on the scenario to include CT and mark the practices they added from the provided CT framework. If participants marked "yes" or "maybe" then they marked the CT practices identified in the vignette.

Each vignette was intended to create ambiguity: under some views of CT, certain practices would be identified; under others, no CT (or a more limited set of practices) would be present. All four vignettes are shown in Appendix B. The vignettes are specifically designed to capture how teachers conceptualize CT and apply that view to a given teaching scenario.

STIG^{CT} Reflections

In addition to reflecting on their *teaching*, participants also responded to questions about STIG^{CT} activities throughout their participation. There were three types of reflection: activity, STIG^{CT} session, and lesson seed process reflections. In activity reflections, participants answered a few short questions about the activity they had just engaged in. For example, after exploring different computational simulations about scientific phenomena, participants completed a sheet with the following questions:

1. Which simulation(s) did you explore?
2. If and how did each provide opportunities for children to engage in science learning?
3. If and how did each provide opportunities for children to engage in computational thinking?

Each reflection was tailored to the activity but asked similar questions to those above. These reflections provide information about how teachers viewed their participation in the STIG^{CT} and which activities they found valuable to their—and their students'—learning.

On the other hand, STIG^{CT} session reflections consisted of the same question asked at the end of each of the four sessions: "After today, what questions do you have about computational thinking or how you could incorporate computational thinking into elementary science?" Although responses were typically short (answers to each question span between 1 and 3 sentences), these reflections can inform how teachers' thinking is evolving through participation in the STIG^{CT} and can be a window into areas of interest that participants have, as well as areas of confusion.

Finally, participants reflected once (during the 3rd STIG^{CT} session) about their lesson seed design process. In these reflections, participants were asked to share details about how they approached lesson seed designs. For example, we asked: "how do you get started with the lesson seed?" The full instrument is available in Appendix C. This instrument aimed at understanding how participants valued the lesson seed design activities and how those sessions could be helpful to them in the future.

Lesson Seed Design Videos

After participating in CT activities, participants were tasked with co-designing *lesson seeds*—drafts of lesson plans that integrated CT into science instruction. These design sessions typically involved groups of 4-6 people including teachers, both pre- and in-service, at the same grade level and one or two researchers from the CT→PSTE team. If a mentor-mentee pair was present, they were in the same group. These design sessions took place at 3 of the 4 STIG^{CT} sessions, and the researchers on each group were not fixed. For example, if a group of 2nd grade teachers worked with a co-PI researcher on the February STIG^{CT} session, they may have worked with a graduate assistant in the March session.

During the sessions, participants were given a template (Appendix D) where they had to determine the objective of their science lesson and explain how it would integrate CT practices from the framework. During these interactions, the researchers' role was meant to be equal to teachers; we were not there to supervise the inclusion of CT, but to assist in the lesson plan as co-designers. Typically, sessions involved discussing potential topics to integrate CT, activities that could help students develop CT skills, and tools to use in the classroom. The design sessions were video- and audio-recorded with a still camera at a corner of the room. Each session has also been transcribed to facilitate analysis.

Focus Groups

At the end of the PD experience, teachers participated in focus groups with peers with similar experience. For example, preservice teachers were in their own focus groups, while mentor teachers who were participating in the PD experience for the first time were in a separate group. The focus groups focused on how teachers had implemented CT in their classrooms in the semester that the PD took place, how they felt about integrating CT in the future, and how the $\mathrm{STIG}^{\mathrm{CT}}$ activities had contributed to their understanding of CT. The questions asked during the focus groups are available in Appendix E.

Lesson Plans & Lesson Reflections

As participants of the $\mathrm{STIG}^{\mathrm{CT}}$, teachers were also tasked with devising a science lesson plan that integrated CT, teaching it in their classrooms, and reflecting on their experiences. To complete their participation, teachers had to complete a template (Appendix F) to describe their lesson plan and reflect on their experience to the research team. The template required participants to describe their lesson plans in detail and to provide their perspective on student learning of science and CT, levels of engagement, and suggestions for improvement of the lesson.

Teachers were allowed to create and submit lessons with their mentors, mentees, or colleagues, as long as they submitted individual reflections. We received a total of 11 shared lessons: 10 from mentor-mentee pairs and one from a group of four (two mentors and two mentees) that worked together. There was a total of 22 unique lesson plans submitted.

The submitted lesson plans took various forms—some adopted the 5 E's model (Bybee & Landes, 1990), others adapted their state curriculum sample lessons to include CT, and yet others built on lesson seeds designed in previous sessions to create a more complete lesson plan. Typical responses for each question in the template involved one or more paragraphs.

Field Notes

The STIG^{CT} field notes are a set of transcribed notes from researchers during the STIG^{CT} sessions. The notes were taken with minimal structure: just a few pointers on which aspects of participants' discussions and behaviors to focus on. During each session, some researchers took a role of observer while others facilitated. Observers took more copious notes, and facilitators usually provided a more reflective account *after* the session was over. Typically, 2-5 researchers wrote field notes per session.

Data Collection: CT Integration after the STIG^{CT}

The procedures described above correspond to data collected during the STIG^{CT} for all teachers who participated in the PD. Below, I transition to describe the data collection instruments and procedures that correspond to the second analysis and only involved the focal teachers participating in this dissertation study. This data collection phase consisted of three interviews, each with a different focus. The rationale for conducting three interviews has two main supports. First, I followed Seidman's (2013) recommendations on qualitative interviewing, where he proposes a three-part interviewing structure where interviews allow the researcher to get insight into participants' contexts, their lived experiences, and their reflections on those experiences. Second, I aimed to have at least one interview that focused on each sub-process of CT integration: design, implementation, and reflection.

Each interview was conducted and recorded virtually via Zoom to abide by restrictions due to the COVID-19 pandemic. First, I conducted an interview to understand how teachers had integrated CT in the past year, understand their school context, and capture their reflections on the process of integration. The second interview focused on capturing how teachers designed lessons for CT integration in the year following their STIG^{CT} participation. The third interview aimed to understand how they had implemented those lessons, asking them to recall them as vividly as possible.

All interviews followed a semi-structured format where the conversation was guided by some predetermined questions, but the interviewer expanded questioning and followed conversation threads that emerged during the interview. Semi-structured interviews were particularly fitting for this study, as the format allowed me to respond to the "emerging worldview of the respondent" and provided me with opportunities to obtain insights that I could not foresee when creating interview questions (Merriam, 1988, p. 74).

General Integration and Reflection Interview

The first interview served to assess how teachers saw their integration of CT, get information on the lessons they had implemented, and capture how teachers reflected on the process of integrating CT into science. This initial interview also functioned as an anchor to the following interviews. The lesson design and implementation interviews focused on the lessons that teachers described in this first instance. The full interview protocol is on Appendix G. Some of the guiding questions for this interview were:

- What made you think to integrate CT?
- How did the lessons go?
- Do you think your children engaged in CT?

- What do you think would be necessary for you to integrate CT in the future?

Lesson Design Interview

Through this interview, I intended to capture how teachers approached the task of integrating CT into their lessons; which CT practices they selected to integrate, and why; classroom considerations that affected the activities they designed or CT practices they integrated; their predictions on how activities would develop and potential obstacles; and their confidence level in designing these lessons. The full interview protocol is on Appendix H. Some of the guiding questions for this interview were:

- How did you create this lesson plan?
- Did you base the lesson on an existing lesson?
- What were your goals when designing the lesson?
- Tell me about your decision to integrate CT, which CT practices did you integrate?

Implementation Interview

This third interview focused on capturing how teachers implemented the CT-integrated science lessons they described in the first and second interviews. The interview aimed to capture the language that the teacher used to describe and facilitate CT activities, how the lesson was framed (i.e., the motivation and connections to other classroom learning expressed), and how the lesson was implemented in comparison to its plan. The complete interview protocol is on Appendix I. Some of the guiding questions for this interview were:

- How did you explain or frame this activity for students?
- How did the students react?
- What do you think students were successful at doing during this activity?
- Did this part of the lesson engage students in CT?

Data Analysis: Theoretical Framework

To guide the data analysis of this dissertation, I used the theoretical framework developed by Grossman, Smagorinsky, and Valencia (1999) concerning how teachers appropriate conceptual and practical tools for teaching. The framework has been recently used in other investigations around how teachers integrate instructional innovations or technology into their classrooms (Henning, 2013; Leko & Brownell, 2011; Longhurst et al., 2017; Reynolds, 2012) and is described in detail in the Literature Review section.

This theoretical framework guided the analysis of data to answer both research questions. First, I used the framework to answer RQ1, which focuses on how participation in the STIG^{CT} impacted CT appropriation. In their presentation of the levels of appropriation, the Grossman et al. also elaborated a list of "factors affecting appropriation" that they observed in their study of preservice teachers. These factors can explain the different levels of appropriation that teachers show in different scenarios and served as a set of codes applied deductively in this study. The framework specifically names two factors: (a) the social context of learning, which includes both the setting where the *teacher* learns about the new pedagogical tool and that where her *students* learn when the teacher implements that tool, and (b) the individual characteristics of the teacher, including the influence of the "apprenticeship of observation," (Lortie, 1975) their personal goals and expectations, and their knowledge and beliefs about the content.

I used these two factors and their sub-levels deductive tool to analyze data around the integration of CT. For example, I labeled considerations of instructional time constraints during lesson seed design session as evidence that the *social context of learning* affects the level of appropriation (in this case, *Lack of appropriation*). On the other hand, I labeled evidence that teachers believe a practice or activity (which could be evidenced in an activity reflection) is developmentally inappropriate for their young learners as a

Characteristic of the learner that impacts the level of appropriation of that CT practice (see section below for detailed analytic procedures).

Regarding RQ2, which focuses on how teachers integrate CT in their science teaching after participation, the framework served a diminished role. Instead, I focused on inductively identifying themes in teachers' experiences integrating CT in the year following the STIG^{CT}. I paid particular attention to how teachers described the impact these experiences had on the processes of planning and implementing CT-integrated lessons. These phases are based on the process of integration that the STIG^{CT} modeled and promoted. In the PD, teachers were provided with opportunities to co-design lessons, implement them in their classrooms, and reflect on those experiences. The goal of this second phase of the study was to understand how those processes had unfolded after the PD ended.

While Grossman et al.'s theoretical framework (1999) was a productive tool to analyze the data in this study, it also has some limitations that must be addressed. For instance, the framework was developed from studies on *preservice* teacher learning and focused on how appropriation of practices learned in the university classroom played out when new teachers entered the workforce. However, teachers in this study participated as both pre- and in-service teachers, meaning that their learning around CT sometimes took place not as novice teachers, but as experienced educators.

Although it is possible that in-service teachers who learn about a new pedagogical tool may evidence different forms of appropriation than pre-service teachers, *all* the STIG^{CT} participants were relatively new to the concepts of CT and computing. This homogeneity in expertise (or lack thereof) likely made it so that in-service teachers approached the new pedagogical tool from a similar initial level of conceptual understanding than that of pre-service teachers.

Additionally, the framework was originally based on experiences with teachers learning to teach English, which is likely to have significantly different pedagogical priorities and goals than science or CT teaching. It is possible that the *content* teachers are learning to teach in this study played a role in the factors that affect how they appropriate the pedagogical tool presented in the STIG^{CT}. However, at this moment, I have no reason to believe that social context, teacher knowledge, and personal characteristics will play a systematically different role in how teachers appropriate CT to teach science than it would if they were appropriating an English pedagogical tool.

Data Analysis

The data analysis for this study was conducted in two phases. First, I analyzed and coded data pertinent to RQ1. The first research question of this study*, How do teachers participating in a CT-focused PD experience appropriate CT to integrate it into their science teaching?* focuses on how teachers reach different levels of appropriation after participating in the STIG^{CT}. The general strategy for all data analyses was to generate descriptions of each case (Yin, 1994). As Yin recommends, this analytical strategy was guided by a “descriptive framework that organizes the case study” (p. 104). For this study, the descriptive framework to answer RQ1 is composed of three elements. On one hand, there are two main factors identified by Grossman et al. (1999) as affecting appropriation: the social context of learning and the characteristics of the teacher. On the other, an additional important factor differentiates each level of appropriation: teachers’ conceptual understanding. With that guiding framework, I aimed to understand *what* level of appropriation the data suggests each participant reached, and how each of the three elements contributed to that appropriation level.

For each of the 34 teachers who completed their participation in the STIG^{CT}, I coded their final lesson designs and their associated reflections to determine the extent of each teacher’s CT appropriation. Because some teachers were paired as mentor and mentees, I analyzed a total of 22 lessons. When teachers were paired, the appropriation level demonstrated by their lesson was assigned to both teachers.

To make the determination of the level of appropriation a lesson demonstrated, I used the STIG^{CT}'s intended outcome as the definition of the pedagogical tool and compared the lesson's evidence of achieving that outcome. Specifically, the PD program aimed to support teachers in integrating CT as a way that contributes to science learning and increases students' understanding of and confidence with computing. Therefore, to fully appropriate CT as a pedagogical tool, teachers' lessons had to (a) introduce students to concepts of computing and (b) do so in service of science learning.

Using Grossman et al.'s levels of appropriation, I found that a majority of teachers (25) were only appropriating surface features of the pedagogical tool, with a smaller group (9) appropriating labels and one teacher appropriating CT at a conceptual level. The difficulty in reaching the conceptual level came from the dual requirement of designing lessons that introduced students to computing concepts *and* did so in the service of science learning.

Most lessons met one of those criteria but failed the other. For example, some lessons clearly introduced students to computing concepts by engaging them in block-based programming. However, those programming activities were mostly separated from science learning and only used science as a theme for the programming exercise. Conversely, other teachers used computational simulations in their lessons, which were well integrated into their science topics. However, they did not discuss the computing concepts behind those simulations, missing the opportunity to introduce students to those concepts.

In summary, this first analysis provided an overly simplistic set of findings, where a majority of teachers appropriated surface features of CT as a tool for science learning. Therefore, I set out to conduct a second analysis that would uncover differences in how teachers appropriated CT, even in cases where their *level* of appropriation was identical.

Beyond Grossman et al.'s model

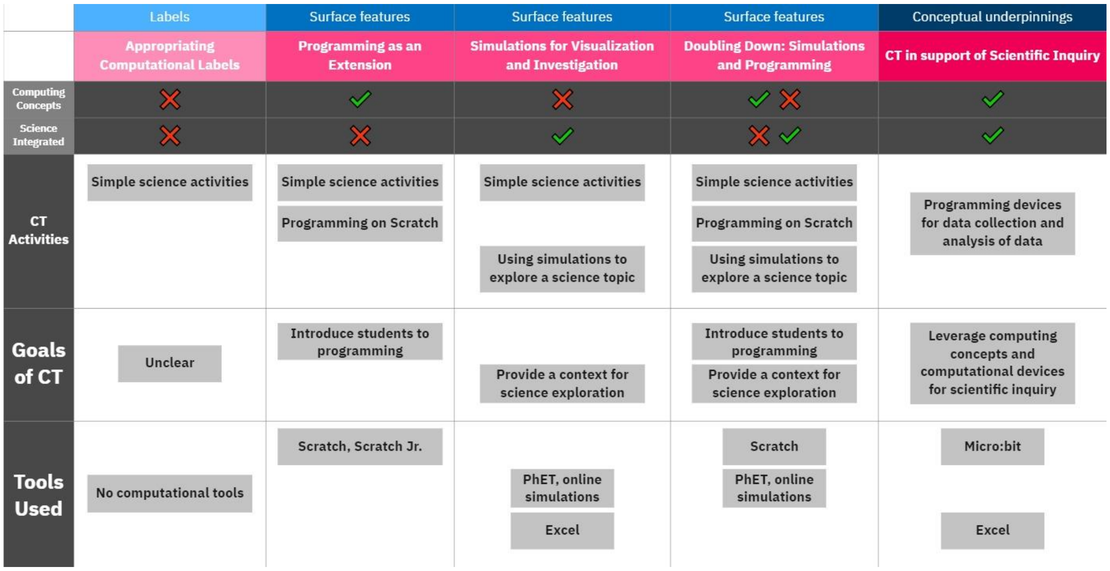
While my initial analysis using Grossman et al.'s framework showed that a vast majority of teachers appropriated surface features of CT, it was also clear that teachers who reached the same level had integrated CT in qualitatively different ways. There were particular differences in how groups of teachers addressed each of the two criteria for reaching the conceptual level of appropriation. So, to better understand how teachers appropriated CT at a deeper level, I conducted a more flexible, inductive analysis that aimed at illuminating *how* teachers appropriated CT instead of *how far* they did so in a strictly hierarchical appropriation scale like Grossman et al.'s model.

This second analysis allowed me to find patterns in lessons across multiple dimensions. Specifically, I found that lessons could be grouped based on:

- which features of CT they appropriated
- the activities teachers described as engaging students in CT
- the implicit or explicit goals of integrating CT practices in the lesson, and
- the tools that teachers used to engage students in CT.

From this analysis, I created five profiles that describe the varied ways in which teachers appropriated CT and provide further insight into the process of CT appropriation than Grossman et al.'s levels had initially provided (Figure 4). Each profile shows a different way of appropriating CT and varies across the dimensions listed above:

1. Appropriating Computational Labels
2. Programming as an Extension
3. Simulations for Visualization and Investigation
4. Doubling Down: Simulations and Programming
5. CT in Support of Scientific Inquiry



	Labels	Surface features	Surface features	Surface features	Conceptual underpinnings
	Appropriating Computational Labels	Programming as an Extension	Simulations for Visualization and Investigation	Doubling Down: Simulations and Programming	CT in support of Scientific Inquiry
Computing Concepts	✗	✓	✗	✓ ✗	✓
Science Integrated	✗	✗	✓	✗ ✓	✓
CT Activities	Simple science activities	Simple science activities Programming on Scratch	Simple science activities Using simulations to explore a science topic	Simple science activities Programming on Scratch Using simulations to explore a science topic	Programming devices for data collection and analysis of data
Goals of CT	Unclear	Introduce students to programming	Provide a context for science exploration	Introduce students to programming Provide a context for science exploration	Leverage computing concepts and computational devices for scientific inquiry
Tools Used	No computational tools	Scratch, Scratch Jr.	PhET, online simulations Excel	Scratch PhET, online simulations	Micro:bit Excel

Figure 4. Profiles of appropriation and their dimensions.

The profiles maintain a relationship to Grossman et al.'s levels but add variations to that categorization (Figure 5). While each profile does not constitute an ordered "level", the profiles as a group still show a scale of appropriation. The first profile, Appropriating Computational Labels, represents the lowest level of appropriation while the fifth, Appropriating CT for Scientific Inquiry, represents the highest. However, the three profiles in-between do not represent an increasingly complex level of appropriation—they are variations of appropriation styles that fall under the Surface level in Grossman et al.'s framework.

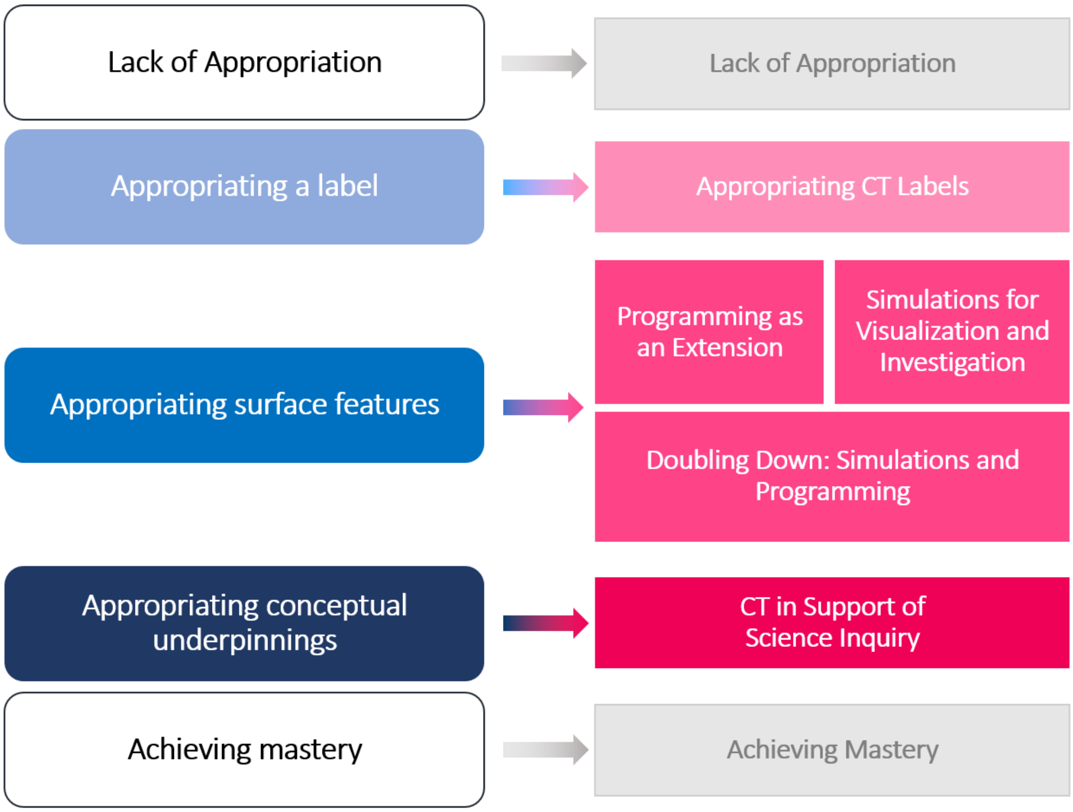


Figure 5. Appropriation levels and their relationship to the five profiles describing appropriation during the STIG^{CT}.

After determining which profile each teacher belonged to as determined by their lessons, I continued to analyze other data to capture the different factors that impacted that appropriation. Since the concern with Grossman et al.'s framework had to do with the differentiation between Surface and Conceptual levels but not with the factors that determine appropriation, I decided to keep those factors as a deductive schema. For each teacher, I coded their interactions during lesson co-design sessions, written reflections, focus group responses, survey responses, vignette responses, and drawings for each of the three factors impacting appropriation: social context of learning, personal characteristics, and conceptual understanding (Figure 6).

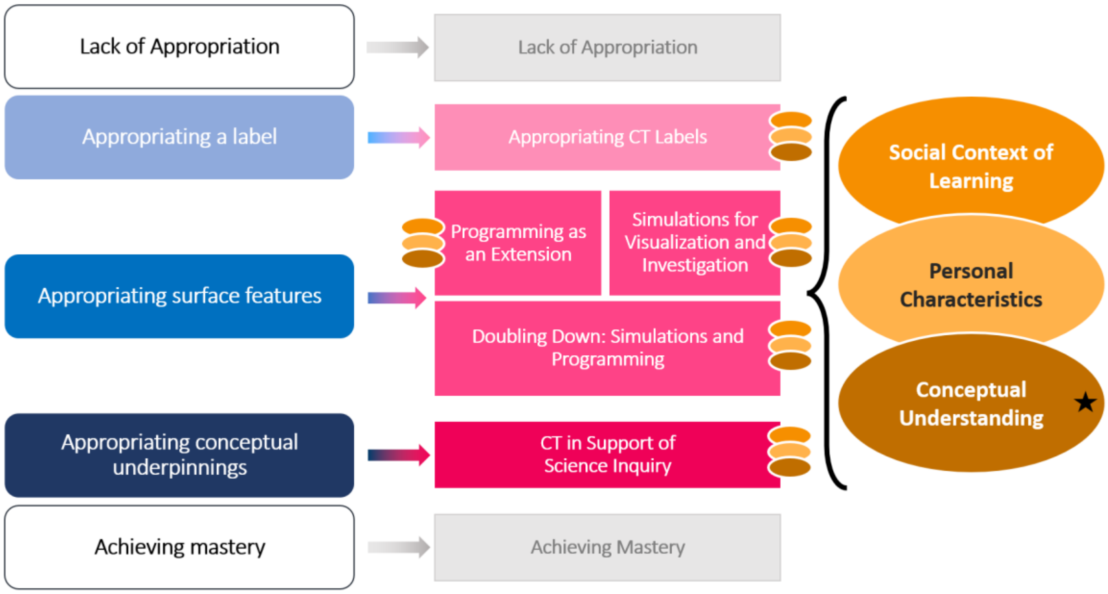


Figure 6. Analysis process from deductively applying Grossman et al.'s (1999) levels of appropriation to lesson plans, to inductively determining the five profiles, to deductively applying the three factors to the remaining STIG^{CT} data.

Once that coding was complete, I employed an inductive coding strategy abstracting generalizations from specific data points (Bogdan & Biklen, 2007). Specifically, I read the data looking for "regularities and patterns" (p. 164) and particularly focused on capturing commonalities around each of the factors for each *profile* of appropriation.

Case Study Analysis

In the second phase of the study, aimed at answering RQ2, I conducted a similar two-phase analysis, but this time focused on the three interviews that each of the case study teachers participated in. First, after conducting and reading the interviews, I coded them deductively for the three subprocesses of integration: designing, implementing, and reflecting.

Second, I inductively searched for themes in each case that would run *across* the three subprocesses of integration (designing, implementing, reflecting.) I used these themes to organize each case and describe each teacher’s story of appropriation from their STIG^{CT} participation to their implementation in their schools.

Validity

As a two-part qualitative study, this dissertation has different arguments for validity on each section. In the first part, concerning the study of teachers’ appropriation of CT during the STIG^{CT}, I used two strategies to enhance the validity of my analysis (Merriam, 2009). First, I corroborated my categorization of the lesson plans with analyses done by other members of the STIG^{CT} team through peer review and examination. In their analyses, they also found that teachers integrated CT practices in distinct patterns, which resemble the five profiles in this study. For example, they noticed groups of teachers who integrated only coding CT practices, and others who integrated simulation activities instead. In fact, the definition and clarification of the two criteria that determined a conceptual level of appropriation in the STIG^{CT} was the result of a process of discussion of the lessons of the PD with the research team.

The second strategy to increase validity in the first part of the dissertation is the triangulation of data collection methods. Once the profiles were determined, my analysis of STIG^{CT} data included a plethora of data including surveys, observations, focus groups, and written reflections. The patterns for each profile concerning the social context, personal characteristics, and conceptual understanding that impacted appropriation emerged through multiple sources of data. For example, as detailed below, comments about the role of curriculum in limiting CT integration that teachers expressed during lesson co-design sessions were echoed during focus groups and written reflections. This triangulation process made it more likely that the patterns I found in the data accurately reflect the phenomenon of CT appropriation.

In the second part of the study, regarding the five teachers and their integration of CT after the STIG^{CT}, I was not able to discuss the data with peers as the project had concluded and I was not able to collaborate with others on such extensive data analysis. However, I continued the strategy of triangulation, this time focusing by checking that the themes I extracted from the data were present in multiple interviews with each teacher and spanned all three processes of planning, implementing, and reflecting on CT-integrated lessons.

Chapter 4: Group-level Findings

Teachers appropriated CT as a pedagogical tool in various ways. Expectedly, teachers with different degrees of confidence in their own learning and comfort with CT; beliefs about the value of CT for science learning; judgments of developmental appropriateness; resource availability; peer and administrative support; and experience in the classroom had diverse ways of integrating CT into their teaching.

The first analysis, using Grossman et al.'s (1999) framework, resulted in an initial large grain-size set of findings. A total of 9 teachers appropriated only the labels of the pedagogical tool, as they neither introduced their students to computing concepts nor integrated these concepts into science learning. A majority of participants (24) reached the next level: appropriating surface features. These teachers integrated CT in a way that did not meet both criteria for reaching the conceptual level. Specifically, they either missed the opportunity to introduce students to computing concepts when integrating a computational tool into a science lesson or, conversely, did not integrate their introduction of computing into the science learning process. In a few cases, teachers created two-part lessons where each part fell short of meeting both criteria at the same time. I deemed these cases as reaching a surface level appropriation because they essentially combined two *separate* activities that represented a surface level instead of integrating one unified activity that met the goals of the pedagogical tool as intended in the STIG^{CT}.

Importantly, most of the teachers who reached a surface level appropriation worked either as mentor-mentee pairs or as a group. Therefore, while a majority of participants reached this level, they, as a group, represent 11 submitted unique lessons—a number much closer to those who reached the labels level only (9).

One teacher did reach a conceptual level of appropriation, meeting both criteria. No teachers failed to appropriate CT at all. This seemingly positive note is likely due to the requirements of the PD series. In order to complete their participation in the STIG^{CT} (and receive their stipend) teachers were required to integrate CT into *at least* one lesson and reflect on their experience. It is likely that teachers who did not have a legitimate opportunity to appropriate CT would instead appropriate CT labels and make an effort to describe their typical science lesson using CT language to comply with participation requirements.

This motivation to appropriate CT (at least its labels) emerging from the study requirements may have resulted in an overrepresentation of teachers who appropriated CT labels. Without the requirement of the STIG^{CT}, it is possible that some of these teachers would not have appropriated CT at all. Nevertheless, the distinction between those who would not have appropriated CT without the study's requirements and those who appropriated labels may be less meaningful, as they both represent teachers who did not execute the PD's intended instructional transformation. At the same time, no teachers reached a mastery level appropriation, which was expected given that mastery as described by Grossman et al. requires prolonged experimentation with the pedagogical tool—something the STIG^{CT} was unable to capture.

Profiles of CT Appropriation

To better represent the data of teachers' appropriation process, I present my findings as a set of profiles of appropriation (Table 3 below). The profiles are first organized by how teachers in them met each of the two criteria for appropriating CT at a conceptual level. For instance, the first profile describes cases where the lessons neither introduced students to computing nor did so in a way that promoted science learning. The last profile describes the case where the teacher met both criteria.

Additionally, each profile shows a pattern across three dimensions of appropriation: teachers engaged students in similar CT activities, ascribed similar goals to CT in their lessons, and/or used similar CT tools. Through these groupings, I intend to communicate how teachers integrated CT into their lessons and provide a representative description of the factors that impacted that appropriation (Figure 4).

As these profiles emerged from the initial categorization based on Grossman et al.'s framework, I retain the three factors described by the authors as key influences of appropriation. Specifically, when describing each profile, I attend to aspects of conceptual understanding, characteristics of the learner, and circumstances of the learning environment. These categories provide a useful structure for understanding how each factor impacted CT appropriation across the profiles.

Table 3. Profiles of appropriation and the factors that influenced them.

	Appropriating Computational Labels	**Programming as an Extension**	**Simulations for Visualization & Investigation**	**Simulations & Programming**	**CT in Support of Scientific Inquiry**
No. of Teachers	9	5	16	4	1
App. level	Labels	Surface	Surface	Surface	Conceptual
Profile Description	*Teachers designed a typical science lesson while applying labels from the provided CT framework to describe the activities they designed.*	*Teachers integrated a programming activity into the end of their lesson as a way of demonstrating the learning that students had acquired through the first parts of it.*	*Teachers integrated a computational simulation for students to visualize a scientific phenomenon, set up different scenarios by adjusting simulation settings, and record the results of running the simulation.*	*This profile constitutes a combination of two profiles previously described. Teachers integrated both simulations as an activity and programming as an extension in their lessons.*	*Teacher integrated multiple CT practices that supported different parts of a multi-week scientific inquiry process.*
Conceptual Understanding	Some interpreted CT very broadly, others more in line with researchers, and saw limitations in their own lesson designs.	Diverse conceptualizations, from broad where very common activities count as CT to narrow views of CT as robotics and programming.	Inquisitive about the boundaries and nature of CT, whether certain activities would count as meeting the requirements of CT, and the differences between scientific inquiry and CT.	Mentors had preexisting knowledge of CT from previous CT PD and knew about tools like Scratch before the STIG^{CT} started.	Inquisitive about the boundaries and nature of CT, whether certain activities would count as meeting the requirements of CT, and the differences between scientific inquiry and CT.
Social context of learning and teaching	Mentors or school not particularly supportive about integration. Existing curriculum and lower grades education clashed with CT expectations	Teachers from almost every grade, of every type of participant. Designed lessons separately, but all participated in STIG^{CT} Scratch demo where programming was suggested as an assessment activity.	Almost all mentor-mentee pairs, mostly from 4th grade and concentrated in a few schools. Dissatisfied with current science curriculum, which clashed with CT integration expectations.	Mentor and mentee pairs in 5th grade. Mentors had other CT PD and leadership in science education.	Critical of current science curriculum but has support from admin to make changes in science teaching. She has a science education leadership position within her school.
Characteristics of learner	Residents without mentors who had concerns about developmental appropriateness	Variability around their confidence with programming, developmental appropriateness beliefs.	Believed simulations were an easy way to get started with CT that more seamlessly fit with existing curriculum. Mentor teachers were uncomfortable with or scared of programming.	Excited about integration, believed that their students could engage with simulations and programming without requiring much instruction; believed students would surpass their own programming ability.	Believed students would surpass their own programming ability, and that students do not get enough programming in their typical schooling.

Appropriating Computational Thinking Labels

This profile describes a type of appropriation primarily constituted by teachers who engaged students in similar activities, but only reached a labels level of appropriation. Each of the 9 teachers in this profile designed typical science lessons while appropriating labels from the provided CT framework to describe the activities they designed. Teachers in this category typically created lessons with simple scientific practices like having their students observe a phenomenon and write qualitative notes about it; measure some data (like plant growth) over time; and openly explore solutions to a problem—like testing the efficiency of different “bird beaks” to pick up diverse food items. The integration of CT teachers described did not have clear goals and the lessons did not include any computational tools.

The categorization of these appropriation cases as Appropriation Computational Thinking Labels is warranted by the absence of computing activities and concepts in the lessons designed. For example, when students observed a phenomenon and wrote notes, they did not use computational devices to help them in their observations or data collection. Similarly, when they tested different “beaks,” they did not use computational concepts such as algorithms to write their instructions for consistent testing. Likewise, activities that teachers labeled as the CT practice *Breaking problems into smaller parts* did not require that those parts could be executed by a computer—no computing concepts came into play when determining those parts or possible solutions.

As no computing concepts were properly introduced, there was no opportunity to integrate them into the process of science learning, which meant that these lessons did not meet either of the criteria for reaching a Conceptual level of appropriation.

Social Context

Teachers who demonstrated these appropriations had a number of commonalities that likely influenced their integration of CT. Most (8 out of 9, or 89%) were residents, meaning that they were participating in some of their first classroom teaching experiences, and all except for one were participating in the STIG^{CT} *without* their mentors. Some of the participants commented on the added difficulty of having to design lessons that their mentors—who sometimes did not know what CT was—would support:

> *Question: Do you believe your mentor teacher would be open to integrating CT into science?*
>
> *She—I think she would be open to the idea, but I don't think she would make changes (unidentified resident, focus group).*
>
> *My mentor is very old school, so I don't see it happening. And also, we don't have technology whatsoever in my classroom. So that would be another issue. (R58, focus group)*
>
> *I would also say I don't think he would be as open to it unless it was more of an extension activity. But, like, to introduce it to modify the lesson itself, he'd be more hesitant to do so (unidentified resident, focus group).*
>
> *mentors don't use CT within lessons or don't know they are using CT (R56 & R58, lesson seed planning reflection)*

The difficulty in introducing a pedagogical innovation without support from mentors seemed to be exacerbated by the status of science education in the schools where teachers worked. When these participants described their experiences in focus groups, they often criticized how school administrations and counties focused on reading and writing as priorities, leaving little instructional time to science. They also shared that sometimes even the already limited time allocated for science ceded to remedial activities on reading and writing.

During the constrained instructional time for science, teachers expressed that the STIG^{CT}'s expectation to integrate CT conflicted with the rigidity of science teaching in their schools. For example, a participant shared that, in her school, teachers used flip charts—a type of pre-made lesson slide—to teach each science lesson, and that integrating CT would require changing the school-wide flip chart designs. She was skeptical of her ability as a resident to enact such a widespread change. Another teacher also shared that her opportunities to integrate CT were constrained by the use of "scripted curriculum" and an expectation that science lessons must meet certain “indicators”—CT not being one of them. These constraints became apparent when teachers were co-designing lessons during the STIG^{CT} that did not conform to the traditions of science teaching in their schools:

> *I really think I need to see science in a different classroom, because this [CT lesson design] I like, because this doesn’t look like anything in my room at all. It’s like—in my classroom, it’s a lesson, and once the lesson is over, it’s done with. We don’t do hypotheses. We don’t make games. We just kind of roll with what the curriculum has. (R13, lesson design session)*

Personal Characteristics

Another common aspect of teachers in this profile was the grade band they taught. All of the teachers in this category taught in the lower grades (1st through 3rd) which, while itself may be an aspect of the social context of teachers, may explain why a number of them expressed worries about developmental appropriateness during lesson co-design with peers and researchers. For example, teachers in this group expressed that some of the CT resources presented in the STIG^{CT} were incompatible with the level of support that young learners needed to complete lessons:

> *Even for ScratchJr [a programming environment designed for pre-reading children], I feel like it's going to be more like teacher-centered than student-centered. You need to kind of make sure you follow with them throughout each step. I cannot just say, "Here's ScratchJr, go ahead." No. That would be a disaster. (R56, focus group)*

These beliefs about developmental appropriateness seemed to impact how teachers appropriated CT. In focus groups, they indicated that they simply did not think their children could engage in more complex practices than basic data collection, which can partially explain why the lessons they designed did not move beyond simple science activities.

Conceptual Understanding

In terms of conceptual understanding, the teachers in this profile were divided into two groups. First, there were four cases of teachers who interpreted CT very broadly, applying the labels of the CT framework to various activities regardless of the presence of a computational aspect. For example, when designing lessons, teachers with this broad view of CT would label a discussion of the recycling process as "breaking down problems into smaller parts" and therefore engaging students in CT—despite the fact that the parts of the problem were not broken down in a way that a computer could help solve them. In vignette responses, teachers with this broad perspective were also likely to identify a host of CT practices in each scenario, even those where researchers believed that students were not engaging in CT at all.

However, the rest of the teachers who appropriated CT labels did *not* show a broad perspective of CT. In fact, many demonstrated an ability to properly identify CT practices during lesson co-design—often matching the opinion of the researcher. Some also recognized that their final lessons—which determined their profile of appropriation—should be improved by strengthening the CT aspects of them. In other words, these teachers *understood* the CT practices they were tasked with integrating but did not do so in their lessons.

Profile Conclusions

The finding that these teachers appropriated CT labels after their STIG^{CT} participation while having different ways of conceptualizing CT begins to question the role that *understanding* plays in the appropriation of a pedagogical tool. While Grossman et al. (1999) mention social context and personal characteristics as factors that can influence appropriation, the framework poses knowledge and understanding as they key determinant of a teacher's appropriation level. For half of the teachers in this profile, this claim held true: they had generalized views of CT that led them to apply the labels of the framework to simple science practices.

However, about half the teachers in this profile showed a conceptual understanding of CT that seemed sophisticated and relatively close to how researchers conceptualized CT. Instead, what seemed to drive teachers' low level of appropriation in this profile were aspects of the context where they worked and their beliefs about their students. Specifically, almost all of the teachers in this profile were residents participating without their mentors. The difficulties of trying to innovate in the classroom as an intern—especially in schools where instruction is standardized—seemed to greatly constrain the types of CT practices that teachers aimed to integrate.

These obstacles, coupled with beliefs that students in lower grades would be unlikely to successfully engage with complex CT practices anyways, encouraged teachers to take a conservative approach to integration. While these integrations of CT showed a low level of appropriation that even some of the teachers recognized, they met several goals for the participants.

On one hand, they met the requirements of STIG^{CT} participation, as designing and implementing a CT-infused lesson was sufficient—regardless of the level of sophistication that lesson displayed. On the other hand, the appropriation of labels only allowed teachers to teach lessons they already knew they could implement and avoided confronting mentors or administrations who may not be supportive to CT as an innovation. To be clear, I am not suggesting that participants who fit this profile and had a good understanding of CT purposefully appropriated labels only to avoid the hard work of designing and implementing an innovative lesson. It seems more likely that, constrained by a context that was unsupportive of innovation, they decided to take a safer (or less disruptive) approach to integration.

Programming as an Extension

The second profile of appropriation is the first of three that reached a surface level appropriation. The 5 teachers in this profile integrated a programming activity into the end of their lesson as a way of demonstrating the learning that students had acquired through the first parts of it. They all used the same tool (Scratch) with the same goal: introducing students to programming concepts. The beginning parts of each lesson in this category showed great variability. Teachers tasked students with finding facts about a scientific topic on the internet, showed them videos of scientific phenomena with age-appropriate explanations, or engaged them in brainstorming and discussion on scientific processes.

On the other hand, the CT integration portion of each lesson was remarkably similar to each other—and therefore warranted its own profile. Teachers in this category asked students to program an animation of what they had learned (whether it was related to weather, animal adaptations, or electricity and circuits) by using Scratch and ScratchJr. In other words, the programming was always integrated as an extension of more typical science lesson activities. An important aspect of these lessons is that the programming activity, relegated to the end of the lesson, was meant to be a *demonstration* of student learning—not necessarily an intricate part of the learning process.

These lessons, then, showed a type of surface level appropriation where teachers met one criterion but not the other to reach a conceptual level of appropriation. Specifically, teachers clearly introduced students to concepts of computing, as learners had to engage with block-based programming and learn how to create their own animations through commands. However, these activities were designed as extensions of the science lesson—by definition, they were not *integrated*.

Particularly, teachers described these lessons as opportunities for them to assess student understanding of the science topic they had just covered. In other words, they weren't meant to support students in *learning* any content, they served an assessment function. Some could argue that, by creating an animation of a science phenomenon, the students may be reflecting on the topic and therefore cementing their learning of it. However, the teachers in this profile did not describe their activities with that intent—the goal of Scratch was simply to introduce programming concepts.

Social Context

Just like the beginning part of each of the lessons of teachers in this profile, factors influencing appropriation were vastly different among participants. The five teachers who appropriated CT by implementing programming as an extension spanned all elementary grades and STIG^{CT} experiences: a 1st grade mentor-mentee pair, a 3rd grade returning mentor, a 4th grade returning resident, and a 5th grade resident. They also taught in different schools spanning four different counties. Interestingly, none of the teachers shared a co-design lesson with each other (except for the mentor-mentee pair who was always together).

Personal Characteristics

Teachers' personal characteristics also did not reveal clear patterns. For example, teachers' beliefs about students' abilities varied among participants who appropriated CT in this way. This disparity is illustrated by the differences between two specific teachers who appropriated CT through Programming as an Extension. On one hand, a 1st grade teacher believed that her students (who were labeled as Talented and Gifted [TAG]) could handily engage in programming in ScratchJr and would learn it even quicker than adults:

> *My mentor and I were so surprised by how quickly our students were able to pick up Scratch Jr. She and I struggled with Scratch and it even took us a few weeks to become comfortable using Scratch Jr. Our students, on the other hand, immediately caught on and mastered it very quickly. (R32, lesson reflection)*

On the other hand, a 5th grade teacher worried about introducing something as complex as programming to her students, and asked questions about how best to incorporate CT with students who have "little foundational knowledge" on the topic.

Conceptual Understanding

Teachers who appropriated CT by integrating programming activities as an extension also seemed to have diverse conceptualizations of CT. Some teachers appeared to describe activities as engaging in CT practices during co-design sessions but then would broadly identify CT in vignette responses. Others saw CT narrowly, with robotics and programming as the obvious enactments of CT and therefore the types of implementations that would count as integration.

Profile Conclusions

The only apparent common denominator among teachers who integrated CT through programming activities is their participation in the STIG^{CT} sessions. The first session may have been particularly impactful. In that first meeting, the researchers led a short Scratch tutorial to demonstrate the tool and explain some basic concepts of programming. We also explicitly mentioned that one way to integrate Scratch in a science lesson could be as a way for students to demonstrate their learning—an extension. We discussed, for example, that students could create an animation that reflected a relationship or process within a science topic they were exploring.

Teachers in this profile seemed to follow this recommendation to a tee. In all of them, teachers used the same tool—Scratch—and with the same purpose: for students to create animations that would show their learning. While it would be logical to think that faithfully following the recommendation of the researchers should represent a conceptual level of appropriation, this case represents an issue that Grossman et al. (1999) anticipated in their framework. The authors stated that surface level appropriations do not only happen due to a teachers' inability to grasp the content. Instead, it is possible that researchers or teacher educators, in an effort to present the content in an understandable way, may omit or over-simplify aspects of the conceptual underpinnings of the pedagogical tool (p. 19).

As our goal in that first meeting was to get teachers comfortable with Scratch as a tool and with programming practices, we inadvertently offered a less-than-ideal example by suggesting that these activities could be integrated as extensions to typical science lessons. And, while the teachers followed our lead in their lesson designs, they do not meet the double criteria necessary to represent a conceptual level of appropriation.

Simulations as a Visualization and Investigation Tool

This is the second profile of three that reached a surface level appropriation. A total of 16 teachers fit this profile, where CT was implemented by integrating a computational simulation into the lesson. The purpose of the simulations was to give students a way to visualize a scientific phenomenon and give them a digital platform where they could set up different scenarios by adjusting simulation settings and record the results of running the simulation. For example, a participant designed a lesson where students explored the concepts of light reflection and refraction by interacting with a PhET simulation. After discussing their initial insights, students were tasked with setting up different conditions in the simulation to determine the nature of a "mystery substance" that had a particular set of refraction and reflection levels.

The lessons from teachers in this profile demonstrate a surface level of appropriation because they meet one of the criteria for reaching the conceptual level but fall short of meeting the other. Specifically, teachers in this profile integrated an activity that used a computational tool (simulations) in service of science learning. However, they missed the opportunity to use these simulations to introduce students to computing concepts by discussing how simulations are created, the computational components that drive them, or the assumptions that the simulations make to provide results.

Social Context

Among these 16 teachers, a few patterns arose in their social context of learning and teaching, their personal characteristics, and their conceptual understanding of CT. Most notably, almost all teachers in this profile were in a mentor-mentee relationship: 6 pairs of mentor-mentees, one mentor with two mentees, and one mentor without a mentee who often designed with her former mentee—now a returning resident. In other words, all of the teachers who integrated CT via a simulation only designed these lessons with a close peer.

Another considerable similarity among these teachers were the grades they taught and the schools they worked in. Half of the 16 teachers came from one school, Marshmallow Elementary (pseudonym), while the remaining teachers came from three different schools. Most (11) teachers taught 4th grade, while a mentor-mentee pair taught 2nd grade and a mentor with two mentees taught 3rd grade. Both mentors and mentees praised the opportunity of participating alongside their peers:

> *I liked, first of all, the resident participating with us, because I think it's more valuable because we're out of the same page. (RM03, focus group)*
>
> *[talking about participating without a mentor] I think it would've been a lot harder to have implemented that one lesson that we had, that we did. It made it so much better doing it, basically co-teaching it, doing it with somebody else. And then also being, talk through the ideas with the other people on my team and (unintelligible) together. So I think having to do it on my own would've been super overwhelming and it would not have gone well. (resident, focus group)*
>
> *I also feel like my mentor has such a strong background in science in general, that having her help with developing the lesson really helped tie everything down together. Otherwise if I would've been by myself, I would've been like, "Don't know where to go from here. How can I make this a science lesson while at the same time trying to make it a CT lesson?" (resident, focus group)*
>
> *Yeah, I agree, because it's also, like they have the, at least my mentor teacher has the curriculum knowledge. And then I have the, maybe, willing to try this and teach the kids. Whereas she's like, literally psyched for two days because she finally learned Google Slides. And so, it's just like she's not comfortable with tech but she's totally in for using it. So it's like her combination of "Oh, look, I think this would be awesome here. Why don't you explore it and then we'll teach it." Because she's totally comfortable, you know, implementing it. She's just not comfortable using it herself. And so I think that combo, you know, worked really well. (R36, focus group)*

Some teachers also specifically highlighted the benefits of working with teachers in their same school:

> *It helped that [RM03] and I are on the same team, because we were definitely more invested in the CT. But everyone else in the school, no one has a clue. You know, the other teachers, they don't know what it is. (RM02, focus group)*

Interestingly, teachers who fit this profile echoed dissatisfaction with the status of science at their schools and the lack of instructional time to implement the CT lessons they designed. Like those who appropriated computational labels and those who integrated CT through programming extension activities, these educators felt like their schools prioritized reading, writing, and math—often leaving science a relegated position.

More specifically, teachers in this profile complained about stale science curricula that presented science in boring ways and were attracted to the potential of simulations to re-engage their students in science learning. For instance, one teacher with more than 30 years of experience expressed that CT integration had made her "more excited about teaching science than [she] has been in a couple years" while another shared that "engagement" was the primary reason she had integrated CT.

However, the potential of CT and simulations to engage students in the classroom also met common barriers associated with traditional science education and issues of elementary school. For example, one teacher who expressed frequently having issues of classroom management worried that integrating CT—which sometimes expects self-directed learning—would only exacerbate those issues. A 2nd grade teacher, instead, talked about the difficulty of implementing CT when it is not in the science curriculum, which leaves teachers with little guidance and support. And a pair of teachers discussed how integrating CT required a shift in *their own* mindsets, which were heavily influenced by typical teacher-centered science instruction.

Personal Characteristics

Teachers who integrated CT through simulations had a few common beliefs that may have contributed to their lesson design decisions. Multiple teachers explicitly described simulations as an easy way to get started on the integration of CT. For example, a mentor teacher described using simulations as "the simplest way to jump off the boat" in terms of CT integration. Multiple teachers justified the easiness of integrating simulations their alignment with existing standards and science topics. A returning mentor explained that she had integrated a circuit simulation in her lesson because, at the time she participated in the STIG session where that simulation was demoed, she was preparing to teach circuits and light on the following week (RM01).

Other participants made a similar argument, saying that simulations are the easiest STIG tool to integrate because they are already created for teachers and they could go and find simulations for “basically anything” (M03). This perceived low barrier for integration was contrasted with the high requirements of integrating more complex instances of CT, particularly programming or coding. A teacher conveyed this sentiment in a focus group:

> *I feel like I've kind of gravitated toward the simulation because that's a comfortable place for me. I get that coding is a part of it, but that's not a comfortable place for me, so I haven't grabbed onto that too well. (M02, focus group)*

This low level of confidence in their ability to understand and integrate programming activities was shared among multiple teachers who integrated CT via simulations—particularly amid more experienced teachers. All but one of all mentors and returning mentors (but no residents) in this group expressed some level of apprehension towards integrating programming or coding activities. For instance, a few teachers described Scratch, which was demoed at a couple of STIG sessions, as being difficult for them to understand:

> *So, I think, like the Scratch, for me, is something that I definitely need to spend more time on. The coding, I—it was difficult for me. (M07, focus group)*
>
> *Well, I feel like it was really hard for me to wrap my head around Scratch. So, to think about my children doing it would be hard (M01, focus group)*
>
> *I <3 that the lessons appear to be more elementary friendly—but this level of Scratch still too hard for me—would be nice to know what lower level Scratch is! (RM03, written reflection)*

This shared apprehension for programming and the perceived low barrier of simulations as a first instance of integration may explain why teachers in this group designed lessons centered around using simulations for visualization or investigation purposes. While 16 teachers fit this profile, it is important to remember that they all designed their lesson in pairs (with a group of three and a solo mentor as exceptions). Therefore, it is possible that these designs are the result of a compromise between the two parties. For example, if one of the teachers in each pair was apprehensive about integrating programming (most likely the mentor or returning mentor), the group could settle for integrating simulations—an easier option in their eyes. A resident explained this dynamic during a focus group, where she said that her mentor's "lack of experience" with programming had limited their ability to try to integrate those practices into the lessons.

Conceptual Understanding

Beyond their commonalities in social context and personal characteristics, teachers who integrated CT via simulations also shared perspectives in their conceptual understanding of CT. Interestingly, a number of teachers in this group were likely to explicitly ask questions about the boundaries and nature of CT, whether certain activities would count as meeting the requirements of CT, and the differences between scientific inquiry and CT. For instance, during lesson co-design sessions, a mentor teacher asked for the difference between a simulation and a video, and a returning mentor was curious on the pedagogical effects of using a simulation *before* students understand the topic and *after* they have experience with it.

In their reflections, teachers in this profile also wondered about the requirements that would qualify a lesson as integrating CT. For example, a mentor teacher wanted to know the difference between a truly integrated CT lesson and one that "just include[ed] certain components like data collection." Other teachers had similar reflections:

> *What components of CT are absolutely essential to have a CT lesson? (R07, written reflection)*
>
> *I am confused how to determine whether or not my lesson seed contains an aspect of CT that is "enough" of a CT concept. (R35, written reflection)*
>
> *Is science inquiry part of the CT thinking?? (RM03, written reflection)*

The inquisitive pattern of teachers in this profile suggests that they were thinking carefully about their integrations of CT, and that they wanted to meet the requirements that researchers had created for their lessons.

Profile Conclusions

Teachers in this profile largely shared a social context, as a majority of them taught in the same grade and a subset worked in the same school. These characteristics of their social context likely contributed to a convergence of lesson designs. Teachers in this profile, who were mostly paired in mentor-mentee teams, often sat together, participated together in co-design sessions (since they were organized by grade) and shared lesson ideas with each other. It is unsurprising then that they designed similar lessons, with shared goals of CT integration and similar computational tools.

The decision to integrate simulations, nevertheless, seems to respond to a combination of social context aspects and personal characteristics. On one hand, teachers in this profile were uniformly dissatisfied with the existing science curriculum and contrasted it with the expectations of CT integration. This contrast can explain why they opted for an integration that would fit their existing curricular obligations. Simulations allowed teachers to comply with the topics their counties mandated while introducing a new computational tool that would "count as CT."

On the other hand, personal characteristics also seemed to push teachers towards integrating simulations and steering away from other practices, like programming. These teachers described an apprehension towards coding and programming—they did not feel comfortable with their understanding of computing concepts and were not in a position to teach their students about it. This combination of social context aspects and personal beliefs was best summarized by teachers' assertion that integrating simulations was the most straightforward way to integrate CT into their lessons.

The choice to go with the "easiest way to jump off the boat" may also respond to a lack of clarity on what CT entails. Teachers in this profile were inquisitive about CT and its boundaries, but often showed confusion on "what counted" and engaged in conversations with researchers trying to clarify their understanding. This ambiguity likely contributed to teachers deciding to integrate CT practices they saw as less complicated and could be directly infused into already existing lessons.

This type of appropriation of CT reached a surface level—particularly because it did not introduce students to computing concepts when they engaged with computational simulations. Teachers' avoidance of discussions around computing when using simulations is consistent with the three factors described above. It is unsurprising that teachers who were not confident about programming and expressed ambiguity about CT did not engage in conversations with their students about computing concepts.

Nevertheless, teachers' integration of CT through computational simulations was clearly in service of science learning. Students used the simulations to explore science topics, set scenarios that would test different ideas and hypotheses, and—in some cases—collected data on their simulation runs. These lessons serve as a promising starting point for more sophisticated CT integration in the future.

Doubling down: Simulations and Programming

This is the last of three profiles that reached a surface level of appropriation. While the number of teachers that fit in this profile is small (4 teachers—two mentor-mentee pairs) and they only represent two lessons, this profile serves an important theoretical role to describe CT appropriation. Specifically, this profile shows that the two criteria needed to reach the conceptual level of appropriation must be met *simultaneously*. Teachers in this profile combined two ways of appropriating CT: they had their students engage with computational simulations *and* included programming activities as extensions to their science lessons. Therefore, this profile constitutes a combination of two profiles previously described.

However, the appropriation of CT described in this profile still only demonstrates a surface level. As explained above, to meet a conceptual level of appropriation, the activities in the lessons must both introduce students to computing concepts and do so in the service of science learning. The activities teachers integrated in these two lessons do not meet those criteria together. Instead, they meet one criterium at a time in separate activities. The engagement with simulations used computational tools to provide students with a platform to investigate a science topic but missed an opportunity to discuss computational concepts involved in those simulations. Conversely, the programming portion of the lesson introduced students to computing concepts but did not relate them to scientific processes—they were only used in the service of creating an animation with science as a topic.

Social Context

The four teachers in this profile constituted two pairs of mentor-mentees. They all taught in the 5th grade, and the two mentors also seemed to be involved in other opportunities of CT learning and had taken leadership positions around science education. One mentor teacher had participated in another CT professional development by Discovery Learning, where she learned about ways to integrate CT in "unplugged" ways. She also explained that she teaches an online course for a local university and had discovered Scratch through that job, eventually sharing it with "the tech person" in her school. The other mentor teacher who fit this profile shared that she had participated in a professional development opportunity around science and technology. She explained that the PD aligned with the STIG as "a lot of the thinking for a lot of the projects [that were presented in the other PD] would be computational thinking ideas." This teacher talked about her heavy involvement in the school's science fair, which provided opportunities to practice the integration of CT in longer projects and with students of all grades.

The two residents who fit this profile also recognized their mentors' involvement:

> *My [mentor] teacher is very big into energy fairs. She brought the energy organization, whatever it is, to our school. And same with science fair. She's very into it. So, she was excited to learn new things about [CT], because she had had the same kind of system going. And then I was like, "Why don't we try these simulations or these things?" And she was really excited to add to it. She's open to it. (R19, focus group)*
>
> *Mine was super excited, as well. We spent so long trying to come up with a science lesson where we could use robots. Because all we wanted to do was use robots. But we just couldn't find anything. That's one of our goals. (R27, focus group)*

Personal Characteristics

In terms of personal characteristics, teachers who fit this profile seemed open to the idea of letting students interact with computational tools without much instruction, even suggesting that students are more proficient with those tools than their teachers:

> *especially with fifth grade, we found it pretty easy to get it going. They—the simulations we've done—[the students] just do it on their own and they discover how it works. And they're awesome with it. (R27, focus group)*
>
> *I'm more like, "OK, let's watch a simulation, then you guys try it." And I'm more with them exploring. (R19, focus group)*
>
> *because I'm old school, want to go by way of: 'let's learn about it, me learn about it, then I'll teach you [the student] how to do it, and then'... But really, it's best to put it out there and see what they can do with it. Get them involved. Next thing you know, they're teaching us about it. (M06, focus group)*
>
> *I mean [the students] teach me. Like, I had a basic understanding of Scratch, but [my mentee] and I are no longer the experts. And I'm like, "Well so-and-so is doing this, so go ask them." So, they really embrace each other. And I feel like they're more comfortable going to each other and they're actually looking for help and they're learning how to do it. (M05, focus group)*

The two mentors in this profile also shared being motivated to integrate CT because they saw computing as an important part of future careers:

> *I mean, these are skills that the kids need to know if they want to have successful careers. So if we don't start teaching them, I feel like we're doing them a disservice. (M05, focus group)*
>
> *There are jobs now that, every year that I go [to this job fair], they have little tables, it's kind of like bar tables, and people sit with these new jobs that I had never heard of because they weren't even in existence two years before. And everything is going towards so many different digital coding, all kinds of things. (M06, focus group)*

They also echoed some beliefs and context characteristics with participants in other profiles. For example, a teacher shared that she “had a hard time picking up on the Scratch thing”—echoing the sentiments of teachers who integrated CT by using simulations. They also shared the insight that integrating simulations was easier, as they aligned with the existing science curriculum they had to teach.

Finally, teachers in this profile seemed to heavily value “engagement” and having students interested in their learning. In their written reflections, they all highlighted that simulations had successfully engaged students. In the case of a mentor-mentee pair, they even extended the allotted time to use simulations because students “could not get off their computers (not even for recess).” They also wanted to add alternative activities to programming for those who were *not* interested in that kind of activity, demonstrating that they valued students’ interest in the science activities they designed.

Conceptual Understanding

In terms of conceptual understanding, the four teachers in this profile seemed to define CT through a technological perspective. They saw multiple applications of CT such as programming robots, using computational simulations, and creating data graphs with computers. However, they were consistently confused by the concept of “unplugged CT” and had a harder time seeing how CT practices would be embodied without computers. They also saw these applications of CT as appropriate for students with high academic levels, which left them wondering how CT should be adapted to “meet the needs of *all* learners.”

Profile Conclusions

The four teachers in this profile were two mentor-mentee pairs that designed lessons including two different types of activities: computational simulations for investigation and programming as extensions. While each of the activities met one of the criteria for reaching a conceptual level of appropriation, the fact that neither activity met both criteria simultaneously resulted in a surface level appropriation.

Although these four teachers reached the same level of appropriation than teachers in the previous two profiles, there are important differences that likely contributed to their decision to include *both* types of activities. First, teachers in this profile saw CT as mostly associated with computers and programming, which seemed to directly influence the types of activities they integrated into their lessons. Being unclear about how to integrate CT through "unplugged" activities, they opted for using computational tools which had no ambiguity about meeting the requirements of counting as CT integrations.

Additionally, teachers had personal characteristics that likely played a role in their decision to integrate simulations and programming activities. On one hand, these teachers echoed those of teachers in profiles who integrated simulations and programming activities individually. Specifically, teachers in this profile saw the integration of simulations as a low-barrier opportunity like teacher sin the Simulations of Investigation and Visualization profile. They also believed that coding and programming were important skills for students' futures, similarly to teachers in the Programming as an Extension profile.

On the other hand, these teachers had certain beliefs that contrasted them with teachers in the other profiles. For instance, teachers in this profile were not hesitant to introduce programming because of their self-perceived lack of expertise. Instead, they thought that students' natural abilities or propensity to quickly master technology allowed them to integrate programming activities even if they were not certain of how to facilitate learning of computing concepts through them.

This profile serves an important conceptual role in determining what successful CT appropriation looks like. Specifically, it demonstrates how teachers can integrate different activities that meet different features of the pedagogical tool and yet those instances may not represent a conceptual level of appropriation. In Grossman et al.'s words (1999), the key for a teacher who appropriated surface features to reach the conceptual level lies in the "understand[ing] of how those features contribute to the conceptual whole" (p. 17).

The lessons of teachers in this profile did not show evidence of these connections between each feature and the conceptual underpinnings of CT as a pedagogical tool. Specifically, the simulations activities had no connection to their underlying computational nature while the programming activities had a superficial connection to science as a topic. The final profile, described below, provides a description of appropriation when those connections *do* exist.

Integrated Computational Thinking to support Scientific Inquiry

This final profile is the only one that represents a conceptual level of appropriation. This profile fit only one teacher and constitutes the integration of multiple CT practices to support a scientific inquiry process. While only one teacher fit this profile, this type of CT appropriation constitutes its own category because it most closely matches the type of integration that the STIG^{CT} researchers hoped to see every teacher enact. This profile also serves an illustrative function to contrast appropriation of CT where both criteria for reaching the conceptual level are met simultaneously from cases where one goal is not met or both are met separately.

The teacher, Ella, was a returning resident who designed a multi-week lesson where students learned about water pollution. Her students discussed how computational devices could help them test water pollution by measuring how much light would be blocked by particles in the water; programmed a micro:bit to measure these light levels; collected and analyzed the data from the micro:bit; and discussed the differences between their controlled experiment and testing water in the real world. As this profile represents a single case, I explain the factors of conceptual understanding, characteristics of the learner, amd social context of the teaching and learning as they contributed to Ella's appropriation of CT.

Social Context

As a first-year teacher, Ella was already occupying a leadership position in science education: she oversaw the Makers Club, an afterschool program where students use Makey-Makeys and other computational tools to create artifacts. She was the only teachers from her school participating in the STIG^{CT} and taught in the 5th grade. She explained that her administration was supportive in making changes to science instruction, giving her the flexibility to integrate CT in more ambitious ways. This level of support, coupled with her experience with computational devices, seemed to make her comfortable in trying out an ambitious CT integration lesson design.

Personal Characteristics

While Ella found support in her social context, she still had a critical eye towards her county's science curriculum:

> *I still would use this lesson if time prevails just for, like, the data collection and analyzing things. Because I see that is amiss, but I also see that required on [standardized tests] and I see that required on their quarterly assessments, but it's not in our curriculum. It's just really not—not on 5th grade. 5th grade I feel like is so much vocabulary. Just like, you know, 'this is what it is, move on.' Another day of, 'this is what it is' and it's not a lot of interaction (lesson seed planning session).*

She also believed, like other teachers, that students have a natural ability with CT tools, and that they may even surpass her own ability to program them, which allowed her to design activities even being unsure of how to teach her students to use the necessary tools.

Conceptual Understanding

Regarding conceptual understanding, Ella was inquisitive about the nature of CT and its relationship to science education. In written reflections, she specifically wondered about the differences between CT and science practices. In two different lesson design sessions, she asked researchers questions about the CT framework provided, how it differed from the CT instruction we had designed for her first year of participation, and whether specific activities would count as systems thinking practices. This inquisitive approach to CT seemed to fuel her ambition to integrate CT using computational devices and overhauling a science unit to center around the experience of programming a micro:bit for a scientific investigation.

However, there was a nuanced aspect of Ella's conceptual understanding of CT that seemed key to making her appropriation reach the Conceptual level. Ella seemed to have fully grasped the idea that CT should be integrated *in the service of science learning*. This idea is best illustrated by comparing how Ella and teachers who Doubled Down approached their integration of programming activities.

Teachers who integrated both simulations *and* programming activities shared aspects of social context, personal characteristics, and conceptual understanding with Ella. They had supportive contexts, were positioned to experiment in the classroom and design lessons, they believed students would succeed with programming activities, and demonstrated a proficient understanding of CT practices.

Yet, the difference between Ella's appropriation of CT and that of the teachers in the Doubled Down profile may lie in the role they attributed to programming activities in their lesson plans. When reflecting on their lessons, teachers who Doubled Down mentioned that students needed additional time to get used to Scratch and to learn the software. In thinking of improvements to the lesson, they all suggested additional time for students to work on Scratch. Yet, their goals with adding more time were not related to connecting the programming activities to science learning—they were content with Scratch being used as an assessment of science understanding. In fact, a mentor-mentee pair in this profile suggested that they could modify the lesson by adding "alternative activities" to students who did not *want* to create a Scratch animation. This indicates that the programming activity was not *central* to how students learned about the topic—it was a method of assessment.

Conversely, Ella's lesson centered around the programming of the micro:bit. The fact that the device would work as a data collection method *forced* conversations about how to abstract the scientific phenomenon (water pollution) to match the capabilities of the micro:bit. The programming of the device also required thinking about how the data collection process should unfold, and which kinds of data would need to be collected. In other words, without the programming activity, Ella's lesson would be completely different—it was not simply an assessment opportunity but a critical component of students' learning about water pollution.

Profile Conclusions

This profile serves an important role in distinguishing the conceptual and surface levels of appropriation of CT. In the lesson that Ella designed, the use of a programmable device (the micro:bit) was integrated in the service of science learning. Importantly, the two criteria for meeting the conceptual level of appropriation were met simultaneously.

As students ideated ways to capture pollution through light sensors, they had to abstract a scientific phenomenon (water pollution) into a computational measure (a light quantity). In this sense, they had to better understand what kinds of pollution are visible and whether pollution is a phenomenon measurable as a continuum. This exercise of programming the micro:bit also helped students to think about computing concepts like how inputs (e.g., light) are represented through numbers and how data collection should be sequenced and specified to be automated. This type of activity highlight the synergy that exists between computing and science—the relationship that researchers try to support teachers in making explicit and leveraging for science learning.

When looking at the factors that impact appropriation, the one teacher who integrated CT at a conceptual level had several positive influences. First, she had a supportive social context that included an afterschool space to develop expertise in science and computational tools. Second, she counted with an administration that encouraged innovation and classroom experimentation. Third, she taught in the 5th grade, where students are most mature in the Elementary grade band and more complex CT practices may be more developmentally appropriate. These aspects seemed to have contributed to Ella's bold plan of integrating programming in support of science inquiry.

These factors are also contrasted with teachers from other profiles. For example, the supportive context Ella worked in is in direct opposition to the contextual barriers to CT integration that multiple teachers in the Appropriating Computational Labels profile identified. Her confidence with programming practices is a sharp contrast with the beliefs of teachers who appropriated CT through simulations and were explicitly apprehensive of coding.

Additionally, Ella had certain beliefs and conceptualizations of CT that promoted an ambitious integration as a way to support scientific inquiry. Particularly, she believed that her students could (and should) successfully engage in complex CT practices. Therefore, the idea that 5th graders could program their own devices for a scientific investigation seemed both plausible *and* productive. At the same time, her curiosity about CT and its relationship to science learning likely promoted an ambitious approach that tested that potential.

Overall, this profile shows a case where multiple factors align to create an ideal situation for CT appropriation. A context supportive of instructional innovation coupled with a curious and knowledgeable teacher resulted in a sophisticated case of CT integration. The task for researchers and stakeholders, then, is to better understand how these factors can be influenced to promote the kinds of CT integration efforts we seek.

Appropriation in the STIG^{CT}

The first analysis in this study intended to answer the research question, *how do teachers participating in a CT-focused PD experience appropriate CT to integrate it into their science teaching?* Teachers participating in the STIG^{CT} appropriated CT in various ways spanning the continuum that Grossman et al. (1999) proposed. While a subset of teachers appropriated only the labels of CT and a teacher reached a Conceptual level of appropriation, a majority of participants appropriated Surface features instead.

The results of this study suggest that the dual criteria established for reaching a Conceptual level of appropriation created different ways of appropriating at this Surface level. Specifically, expecting teachers to adopt CT to simultaneously introduce students to computing concepts *and* facilitate science learning resulted in groups of teachers who appropriated one of those features but not the other. It also resulted in a curious pair of cases where both features were adopted yet separately.

It is important to note that the criteria established to meet the Conceptual level represents *one* perspective of the goal of CT integration, and a different approach would yield different results in this study. For example, if the goal of CT integration were *only* to introduce students to computing, then teachers in the Programming as Extension profile would represent a Conceptual level of appropriation, as they clearly met that goal and integrated authentic computing activities.

However, when the goals of integration also include positioning computing as a way of supporting scientific inquiry and investigations, the assessment of appropriation level changes. In this case, adding programming activities *as an extension*, where they serve only as an assessment tool or are not supporting the learning process, seems to fall short of that goal. This additional goal would reposition the CT integration of teachers in this profile as only a Surface level appropriation.

The reverse is true for those who appropriated CT through Simulations as Visualization and Investigation Tool. Their use of simulations displays an understanding of the Conceptual Underpinnings of using computational tools *for science learning*. But those integrations fail to meet the goal of introducing students to computing concepts. This deficit is evidenced by the lack of conversations around how those computational simulations work and activities where simulations are used as a systematic computational testing tool. Other proponents of CT also argue that the use of computational tools like simulations should be catalysts for learning about computing concepts. For example, researchers suggest that students should “look under the hood” of simulations or “discuss the abstractions and assumptions embedded in models” to begin to understand their computational components (Lee & Malyn-Smith, 2020, p. 16).

Even in the cases where teachers met both goals (Doubling Down) the fact that they did so separately also demonstrates a Surface level of appropriation. If the goals of CT integration are dual, as explained above, then appropriating CT at a Surface level for each goal may not necessarily add up to a Conceptual Underpinnings level of appropriation. The difference between the two levels, according to Grossman et al.’s framework, is the understanding the “theoretical basis that informs and motivates the use of a tool” (p. 17). However, teachers who integrated both (a) simulations without discussing them as computational objects and (b) programming activities as extensions only did *not* show any different type of understanding than those who integrated each practice individually—they simply did both.

In other words, teachers who Doubled Down integrated programming activities, but still did so *as an extension* meant to serve as an assessment of science learning—not an intricate part of content learning. They also integrated simulations *without* conversations around them as computational objects or systematic computational tools. Therefore, their appropriation level seems better described as a Surface level appropriation of two different sets of practices than as a Conceptual level of CT as a pedagogical tool.

On the other hand, Ella, who appropriated CT in support of Scientific Inquiry *did* show a qualitatively different understanding of the purpose of CT practices in science learning. She integrated programming activities as a part of students' investigation of water pollution and used those activities as platforms for students to think about the scientific phenomenon and how it could be captured through a computational process.

These findings around appropriation illuminate the difficulties in integrating CT in science instruction. Even when co-designing lessons with committed residents, teachers, and researchers, reaching the Conceptual level of appropriation was difficult for almost all participants. The requirements of meeting both criteria—and doing so simultaneously—proved too ambitious for teachers with limited opportunities for planning, implementing, and reflecting on CT lessons. Additionally, researchers' focus on explaining the CT framework to teachers and ensuring that lessons designs engaged students in at least *some* CT practices seemed to take away attention from ensuring that those practices maintained a close connection to computing *and* supported science learning.

The reasons behind most teachers reaching the Labels and Surface appropriation levels are multifaceted, but the analysis of the three factors Grossman et al. proposed (social context, personal characteristics, and conceptual understanding) can provide important insights.

How Factors Impact Appropriation Types

The level of appropriation each teacher reached was impacted by the social context of their learning and work, their personal characteristics, and their conceptual understanding of CT. While each profile had its own patterns across these factors, an analysis across all profiles shows additional insights on their impact on CT integration.

Conceptual Understanding

A first important finding is that conceptual understanding did not have a clear relationship with the level or type of appropriation teachers reach. In other words, how teachers integrated CT was not a direct function of how they conceptualized CT or how well they understood the theoretical bases of CT integration. For example, about half the teachers who appropriated CT labels demonstrated a good understanding of CT and conceptualized it similarly to researchers. Additionally, teachers who fit the Programming as Extension profile had different conceptualizations of CT with varying degrees of specificity. Moreover, those who integrated Simulations often asked questions about the boundaries of CT and had different perspectives on those boundaries. Yet, they integrated CT in a very similar way.

Personal Characteristics

A second insight from this study is that personal characteristics, such as pedagogical beliefs and self-efficacy around CT integration, seemed to play a nuanced role in how teachers appropriated CT. For instance, teachers who Appropriated CT Labels shared the belief that some CT practices and tools shown in the STIG^{CT} were not developmentally appropriate for their students. As a result, they had to find alternative ways to integrate CT, which likely contributed to their appropriation at the Labels level.

Moreover, teachers who integrated simulations had low self-efficacy around programming practices and explained their lesson designs as the easiest way to integrate CT—to “jump off the boat.” While they believed that programming could be beneficial to students, they were fearful of being unable to support students in their learning. This lack of confidence in programming practices seemed to be overruled by other beliefs in teachers who *did* integrate programming activities. These teachers shared that *they* had struggled to learn programming but believed that *their students* would naturally have an easier time with integrated programming activities. These teachers, who integrated different programming activities, trusted that their students would “figure it out” and were comfortable positioning learners as the experts in the topic.

The willingness to integrate programming activities even without feeling fully comfortable with them may be further fueled by another belief: that programming and CT are beneficial to students. All teachers who integrated some programming activities talked about how computing was important for students’ future career prospects and saw it as an important skill—regardless of its connection to science. This perspective may also explain why some of these teachers were content with integrating programming activities even if they served as an assessment only. In their view, the development of *any* programming skills was beneficial, even if those skills were more loosely related to science.

Social Context

A third finding from this study is that teachers’ appropriation of CT seemed to be greatly impacted by the social context of their learning. As Grossman et al. (1999) theorized, the social context impacting appropriation included where teachers worked, not just the STIG^{CT} environment. For instance, teachers who appropriated CT labels did not have supportive mentors in their schools who encouraged CT integration. They also described an inflexible curriculum that prevented innovation by residents in their practicums. These environmental constraints left little room for integration and likely impacted their appropriation of CT, leading to a labels level only.

Teachers who were mentors themselves or had their mentors participate in the STIG^{CT} were able to appropriate CT at a higher level, but their social context still impacted their CT integration. For example, about half of those who integrated simulations worked at the same school and co-designed lessons often, which likely led to a convergence of designs with slight modifications for each teacher’s science topic or classroom.

Teachers in this profile were also dissatisfied with the state of science education in their schools—particularly with how "boring" science was for students and how little time they had to teach it. This county- and school-level factor likely made the integration of simulations—which teachers described primarily as engaging and easy to implement—more attractive. In other words, these teachers wanted something that would contrast typical boring instruction by interesting their students while fitting the limited available instructional time. Simulations were a perfect candidate to meet those goals.

Moreover, teachers who had a supportive school environment where they occupied positions of leadership in science education were able to appropriate CT at higher levels. Both mentors who Doubled Down and Ella played a major role in science teaching in their schools by being charge of science fairs, participating in additional science and computing PD, or running CT-related afterschool clubs. They also taught in the 5th grade, which likely made them more confident in their students' ability to handle more complex CT practices like programming and analyzing data extracted from computational devices.

Yet, across these profiles, one dimension of teachers' context—curriculum—seemed to heavily impact appropriation styles. When teachers integrated Programming as an Extension activities, they left the traditional parts of their lesson, which were already meeting curricular obligations, untouched. In other words, they did not fundamentally change *how* the topic was taught or *whether* it was taught—they made their changes to the portion of the lesson that was "extra." Similarly, teachers who integrated Simulations for Visualization and Investigation began co-design sessions by determining their science topics and the complexity of their lessons. Then, they looked for suitable simulations to include in those lessons. In other words, the curriculum served as an untouchable starting point. In this search, teachers would sometimes complain that there was no simulation covering their science topic, or that those available looked too complicated for their students. These styles of integration demonstrate how curriculum loomed over appropriation, influencing the ideas and strategies teachers entertained when designing CT-integrated lessons.

Ideally, integration of CT into science instruction would entail a careful analysis of different factors like students' ability and backgrounds, curriculum, CT practices, and science content to find areas of synergy where integration would be most productive for student learning. However, the evidence from this study points to a less egalitarian perspective of those factors. Instead, teachers saw curriculum as static and tried to *fit* CT into those rigid structures.

Interplay between Factors Impacting Appropriation

These findings on the factors that impact CT appropriation have implications for both theory and practice. Grossman et al.'s (1999) framework of appropriation has the underlying assumption that conceptual understanding is a key factor determining how a teacher appropriates a pedagogical tool. For instance, appropriating a label means that the teacher "learns the name of a tool but *knows* none of its features" (emphasis added; p. 16-17). Similarly, the difference between appropriating at the Surface level and at the Conceptual Underpinnings level comes from *understanding* the theoretical basis of the pedagogical tool. However, Grossman et al. also assert that "grasping and appropriating a tool and using it do not necessarily co-occur for a variety of reasons" (p. 19).

The authors explain that personal characteristics and the social context of learning are other major factors impacting appropriation. For example, they recognize that a teacher may understand the theoretical basis of a pedagogical tool but work in an environment that does not support its implementation, leading to a lack of appropriation. However, the authors are less explicit about how particular relationships between conceptual understanding, social context of learning, and personal characteristics impact appropriation. This study contributes to our understanding of teachers' appropriation of pedagogical tools by providing a detailed analysis of how these factors interplay to result in markedly different types of appropriation.

A comparison of social context of learning across all five profiles suggests that this may be the strongest factor—serving as a "gatekeeper" for appropriation levels (Figure 7). In other words, there is no appropriation of CT without a suitable context where teachers can implement CT. As explained above, even teachers with considerable knowledge of CT and promising personal characteristics were only able to appropriate CT labels when their school context was not conducive to CT implementation. However, the impact of this factor is also evident in the other profiles of integration.

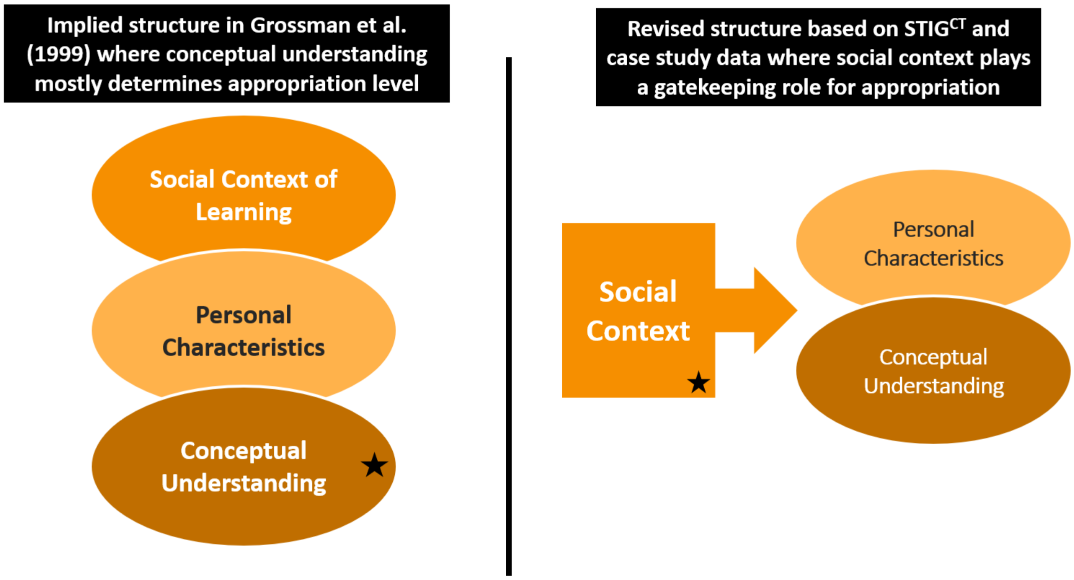


Figure 7. A reframing of the three factors that impact appropriation in the case of CT as a pedagogical tool.

For example, the social context of the STIG^{CT} seemed to contribute to a convergence of appropriation type for teachers who learned alongside their mentors, mentees, and school peers. For residents who integrated CT as Simulations for Visualization and Investigation, this type of integration was at the limit of what their mentors would venture do, and they had compromised to integrate simulations as a team. In this same profile, multiple teachers from the same schools would participate in STIG^{CT} sessions together, co-design lessons, and even help each other find simulations for each curricular unit. While this cooperation likely contributed to teachers integrating appropriate simulations in their lessons, it also likely did not encourage “going beyond” this type of appropriation with additional activities involving programming or data analysis. Importantly, this convergence in appropriation style happened regardless or disparities in how these teachers understood CT or their personal beliefs, leaving knowledge and personal characteristics as relegated factors impacting appropriation.

But, if the social context of learning and working serves as the gatekeeper of integration, then it is important to understand how other factors, like personal characteristics and conceptual understanding, impact appropriation *once the gate is open*. For teachers who *did* have a CT-supportive environment in their schools, appropriation seemed to be mostly impacted by personal characteristics. Specifically, teachers seemed to base their integration on beliefs about their own ability to master different CT practices and their students' potential for success in novel tasks.

In terms of self-efficacy, or beliefs about their own ability, teachers who integrated Simulations were admittedly unconfident about their programming ability, with some even describing being "scared" of coding. So, even if their context *would have supported* an integration of programming activities, they did not feel comfortable teaching something to students that they themselves did not master. Importantly, self-efficacy did not always match CT understanding. Teachers who defined CT and operationalized it similarly to researchers but were not always confident in teaching it to students and did not always integrate programming activities.

Moreover, teachers who *did* integrate programming activities (every other profile except Appropriating CT Labels) were not necessarily overly confident about their ability to integrate those practices. In other words, they also admitted not feeling particularly comfortable with coding. However, other beliefs encouraged them to integrate programming practices. Specifically, teachers who Doubled Down and integrated CT in support of Science Inquiry believed *their students* could successfully engage in programming, even if they were not knowledgeable of those practices as teachers. They were also comfortable with open-ended activities where teachers were not positioned as content experts. Some teachers who integrated CT as Programming as an Extension also shared these beliefs.

The contrast between how Ella and teachers who Doubled Down also shows a nuanced role of conceptual understanding when other factors are equal. In cases where teachers were supported, had flexibility to experiment in the classroom, and believed that their students would succeed in complex CT activities, the difference between reaching the Conceptual and Surface levels of appropriation seemed to lie on a different conceptualization of the role of programming activities in science learning. Ella designed her lesson *around* the programming of a device for a scientific investigation. The teachers who Doubled Down, on the other hand, used the programming activities as methods of assessment of scientific learning.

Implications for CT Teacher Education

The findings from this study question the assumption that knowledge or understanding are the key deciding factors that promote teachers' appropriation levels. That level of protagonism for conceptual understanding only appeared when other factors, like a supportive social context and personal characteristics conducive to CT integration, were present. Instead, these profiles of appropriation suggest that certain combinations of knowledge around the pedagogical tool *and* conditions of social context and personal characteristics work together to determine appropriation levels. Specifically, the findings suggest that combinations of these factors can lead to appropriations of the same *level* but of different qualitative nature. This nuanced point seems particularly relevant when the criteria for reaching the Conceptual level of appropriation is multifaceted. While Grossman et al.'s framework and other teacher learning theories recognize the role of context and personal factors into teacher learning, this study illuminates those interactions in the context of CT integration.

In a recent study, Sherwood et al. (2021) examined how three different models of PD resulted in different pedagogical strategies for CT integration. While teachers in all models had developed similar conceptualizations of CT as a general problem-solving strategy, the way they implemented CT varied based on "instructional and administrative decisions that were unique to those specific school contexts" (p. 258).

Additionally, Jocius et al. (2021) found that PD had successfully changed the goals for integration and beliefs around CT middle- and high-school teachers held, but implementation was still stifled by contextual factors. They specifically mention lack of available technology, flexibility to experiment with the curriculum, and a lack of instructional time as common barriers.

Other studies also support the contention that integration depends on CT knowledge *and* contextual factors. Israel et al. (2015) found that elementary school teachers who were integrating CT into existing curricula and did not have computer science expertise required extensive support. In addition to having CT-knowledgeable technologists and school librarians available, teachers were encouraged by "administrators and coaches [who] publicly acknowledged the computing work" ongoing in classrooms (p. 270). Only after teachers' knowledge of CT developed, they were able to participate as "co-planners" of integrated lessons with coaches, but they still relied on administrative support to integrate complex CT practices in their instruction. In another study on elementary school teachers integrating CT into mathematics curricula, Israel & Lash (2019) found similar barriers to create well-integrated lessons: "(1) commitment to teaching the curriculum with fidelity, (2) need to cover the mathematics content to prepare students for district and state assessments, and (3) belief that the mathematics curriculum was an effective way to teach mathematics concepts" (p. 12).

Yet, the literature around CT and teacher education seems particularly focused on teacher knowledge as the main tool towards instructional transformation. For instance, Sands, Yadav and Good (2018) set out to study teachers' conceptualizations of CT and found that teachers held a variety of conceptions, some more in line with the researchers' view of CT than others. In their discussion and recommendations, they see knowledge as the key to ensuring successful CT classroom implementation: "Our results support the need to develop non-computing teachers' understanding" (p. 161). Most importantly, they argue, PD needs to address potential incorrect conceptions about CT to "develop a thorough understanding" of CT and its pedagogical applications.

Other studies, including my own, have also focused solely on the role of teacher knowledge as a catalyst for instructional change. Corradini et al. (2017) conducted a study to illuminate the "conceptions and misconceptions" of CT Italian teachers hold. I conducted a systematic literature review to find preconceptions of CT that teacher educators could build on (Cabrera, 2019). Rich et al. (2020) studied how teachers' definitions of different CT concepts translated to how they used CT language to describe those practices in the classroom and, in another study, how teachers conceptualized CT concepts before instruction (Rich et al., 2019).

This knowledge-centered perspective was also formalized in the introduction of a CT special issue in the journal *Computing in Human Behavior*. There, Angeli and Giannakos (2019, p. 3) describe the future research direction for Teacher CT Professional Development:

> *For CT education to further develop, teachers need to be systematically prepared in terms of how to design CT learning activities, how to teach CT, how to assess CT, and how to use technologies to teach CT concepts. Thus, teacher professional development programs need to be implemented for in-service teachers, while at the same time teacher educators need to find ways to integrate the teaching of CT in their preservice courses for the better preparation of pre-service teachers.*

However, this perspective puts the full responsibility of CT education on teachers' knowledge of CT lesson design, CT pedagogy, and CT assessment. It does not recognize that teachers' ability to further CT education's progress in their classrooms may—in fact—just as greatly depend on other important factors like their beliefs and context. This study, along with work towards understanding CT integration that expands the scope from teacher's knowledge to their beliefs and context, suggests that changes in knowledge alone are insufficient to promote the instructional transformation we advocate for.

It is important I make clear that this study does not show that knowledge around CT is unimportant for CT integration. Instead, I argue for a reprioritization (and perhaps a demotion of knowledge as *the* key ingredient) of the factors that impact appropriation. This study suggests that a social context that supports CT integration is *necessary* for any integration to happen while CT knowledge and personal beliefs can impact how that integration takes place *once the appropriate context exists*. In fact, this study shows that even if teachers have a less-than-ideal knowledge of CT, they can hold beliefs that can override that lack of knowledge and integrate CT. Teachers who integrated programming, for example, did not have *more* knowledge about coding than their peers—they even shared feelings of apprehension or fear towards it. Yet, their beliefs that their students would succeed in engaging with programming was sufficient to convince them to integrate those practices. At the same time, Israel et al.'s study (2015) shows that teachers initial lack of CT expertise can be ameliorated by proper support from admins, peers, and coaches. Those supports can be sufficient to help teachers integrate CT *while* they develop knowledge about it.

The finding that context and beliefs are important to implementation is not groundbreaking—multiple models of teacher learning include context and beliefs as important factors in a teacher's development (see Ball and Forzani's updated vision of educational research [2007]; the External and Internal Domains in Clarke and Hollingsworth's model of teacher professional growth [2002]; or Gregoire's cognitive–affective model of conceptual change [2007]). However, this study, along with challenging the notion that knowledge is central to instructional change, contributes an account of *how* those factors can impact a teacher's appropriation of a new pedagogical tool. So, if we should not have tunnel vision on teacher knowledge as the catalyst for instructional change, what else *should* we focus on?

Changing Teacher Beliefs

The first additional focus I cover is personal characteristics. Specifically, this study suggests that a set of beliefs can promote more complex types of CT appropriation, while others can shy teachers into simpler integration. The most common belief that prevented teachers from integrating complex CT practices was a worry about CT's developmental appropriateness. Even teachers who *did* integrate programming were worried about over-taxing their students. Yet, they were pleasantly surprised to see that their kids handled those practices with more ease than expected. Developmental appropriateness concerns are logical and expected—after all, computing is often seen as a difficult field and imagining elementary school students mastering it seems counterintuitive.

However, researchers and teacher educators should target these beliefs during PD. Some common strategies may involve introducing teachers to age-appropriate learning progressions that build students' CT skills over time (see Israel & Lash, 2019 for an example). Another possible strategy could be to expose teachers to real-life examples of elementary classrooms engaging in complex CT practices. For example, researchers could show the work of Marina Bers and her team at Tufts University, where they regularly engage preschoolers in coding by playing with the Kibo robot (Sullivan et al., 2017). Nevertheless, the experience of teachers from this study suggests that *trying out* these practices with students is a powerful way of convincing teachers that students can engage in them. Therefore, PD designers could encourage teachers to give these practices a try, even if unsure of the result, as a way to challenge concerns of developmental appropriateness.

A second, related belief that PD designers could target is self-efficacy, or confidence in the ability to integrate and teach CT. This study showed that sometimes teachers had low self-efficacy around CT integration. However, surveys, focus groups, and comments during design sessions showed that instances of low self-efficacy were not about CT *in general*—they were particular to complex practices like programming. In other words, teachers often felt confident about integrating CT in general, but less so about facilitating students' engagement in programming. PD designers should aim to increase confidence in integrating those practices, but how to improve confidence is a complex task. Simply giving time for teachers to try programming may be insufficient, as it can be a frustrating and overwhelming experience without proper support. At the same time, even teachers who feel like they were able to handle tools like Scratch were unconfident about how to *teach* it. For instance, teachers shared being worried about a student asking a programming question that they could not answer. Therefore, increasing confidence in this aspect of CT integration will require a careful and prolonged approach by PD designers.

Yet, a third belief that impacted appropriation in this study may both relieve the burden of increasing confidence in integrating programming practices for PD designers *and* free teachers from feeling like they need to master programming in the first place. Some teachers in this study, while not fully confident about their programming abilities, integrated those practices because they believed *their students* could successfully engage in them. In some ways, they had the opposite belief than those worried about developmental appropriateness—they believed their kids could learn to program better than them as adults. This belief was sufficient to encourage integrating programming activities. However, it also required a different kind of confidence: comfort with positioning the students as experts and teachers as co-learners—an uncommon positionality in most elementary classrooms. PD designers could leverage this dynamic by encouraging teachers to reposition themselves as co-learners with students during CT instruction. In addition to relieving the pressure to become “CT experts”, this positionality can empower students and result in more meaningful learning.

Influencing Teachers’ Social context

If we define the social context of learning as including the school where teachers work, the notion that PD designers should address factors in the social context may seem like an overreach. After all, sometimes teachers attend PD either *outside* of their school (such as at a university like in this study) or do so *without* their administrators or mentors present. However, this study suggests that teachers need a supportive context to appropriate CT at a higher level. Without this supportive environment, they cannot go beyond superficial integration.

This finding is not new either. As other studies reviewed above showed, research shows that administrative support is key to successful implementation. It is time for teacher education researchers to refrain from *only* focusing on teacher learning during PD and simply listing the barriers these teachers face when they try to translate that learning into instruction. Instead, we should specify and research strategies *during PD* that can improve teachers’ context to promote successful integration of CT.

For example, this study suggests that having pre-service teachers and their mentors participate together was beneficial for both parties (see Killen et al., 2020, for a detailed description of the PD model’s affordances). This may be especially true for learning around CT, which is a relatively new concept to novice and experienced teachers alike. PD designers should consider models where teachers with varied levels of expertise work together—particularly if they can co-design and co-teach CT-integrated lessons.

At the same time, PD designers could investigate models of instruction that involve administrators and other school staff like technologists or librarians. Teachers who had other knowledgeable staff or peers in their immediate context were able to appropriate CT at more complex levels. Other research supports this suggestion: Israel et al. (2015) also showed that a supportive context can even ameliorate initial deficiencies in teacher CT expertise. Sherwood et al. (2021) highlighted that PD that involved administrators and embedded coaching created support that was "responsive to teacher needs consistently throughout the year" which promoted successful implementation throughout the school (p. 258).

Finally, PD designers could support teachers to navigate context factors that are difficult to change. For example, multiple teachers, especially those who Appropriated CT Labels, complained about having little time to integrate CT or working with a curriculum that did not allow modifications. It is unlikely that PD can impact instructional priorities or curriculum flexibility (unless administrators are involved as suggested above) but researchers could be more explicit in providing teachers with strategies to work *around* those factors. For example, we could help teachers design multi-day CT-integrated lessons that use short activities to build CT skills over time.

Importantly, PD designers can provide opportunities for teachers to plan for CT integration *in their specific curriculum* as opposed to providing strategies for *general* CT integration. In this study, teachers worked alongside peers and researchers to design lessons with the requirement that they would teach those lessons later. This embeddedness ensured that integration worked *within* existing curricular constraints. However, it is clear that even co-designing with peers and researchers was insufficient to overcome school factors like inflexibility in how a topic is taught. Future studies should investigate how best to support teachers in contexts that are less welcoming to change and CT integration.

Chapter 5: Case Studies

In this section, I present five case studies to answer my second research question: *How do different types of CT appropriation correspond to teachers' reflections of their CT integration within their classrooms?* The unit of analysis in each of these case studies is a different teacher. To present them, I begin by describing the teacher's participation in the STIG^{CT}. Then, I describe their appropriation of CT during their participation in the PD organized in themes that impacted how they integrated CT. Then, I continue with the teacher's integration of CT in the year after the STIG^{CT}. In this section, I organized the data through themes that characterized how each teacher reflected on the design and implementation of two CT-integrated science lessons. The organization of the cases is represented visually on Figure 8. However, in order to present the cases in a way that conveys the story of CT integration of each teacher, the structure is less strictly followed than in presenting the profiles, where each profile attended to three enumerated factors impacting appropriation. At the end of the chapter, I discuss patterns across the cases and how they contribute to our understanding of CT appropriation.

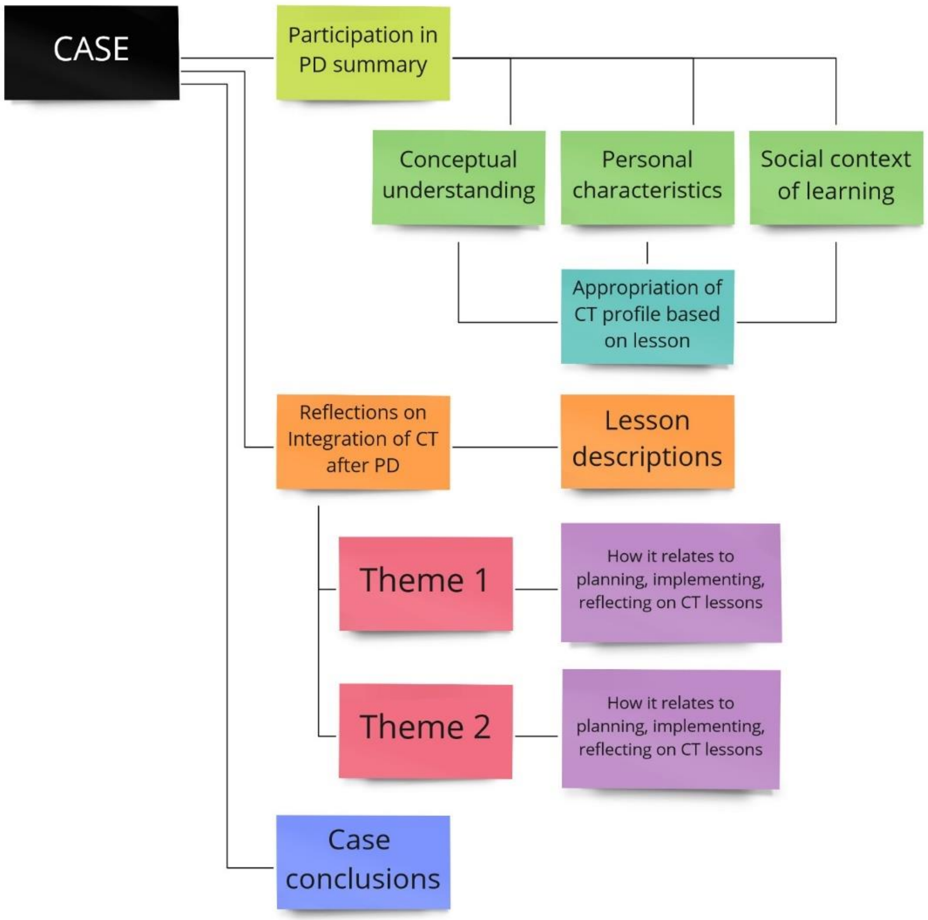


Figure 8. Structure of presentation of case studies.

Anna: CT everywhere "without even realizing it"

Anna's case is an example of a pre-service teacher who appropriated CT labels during the STIG^{CT} and reflected on her integration of CT in the year following the PD through a broad perspective of CT practices in a rigid school context. Anna participated in the STIG^{CT} as a resident without her mentor, placed in a 1st grade class in Blackberry Elementary, where one other resident participant was placed in the 5th grade. During her STIG^{CT} participation, Anna appropriated CT labels as she designed a lesson that resembled typical science instruction but described it using terminology from the CT framework provided to her. Her conceptual understanding of CT was characterized by a broad perspective of CT practices that conflated them often with typical science practices. Her personal beliefs included concerns around student safety and conduct that discouraged her from trying out activities without a clear structure. Her social context was not conducive to innovation: she described her mentor as an "old school" teacher who would be resistant to change; she had little input on the science curriculum, which was established by the school county; and described her classroom as "low tech."

After graduating from the PD, Anna went on to teach 5th grade Math, Science, and Social Studies at a different school. Although she was now a full-time teacher in a different school and teaching the oldest Elementary grade instead of the youngest, her reflections around integrating CT in this new context echoed her experience as a resident in the STIG^{CT}.

Her broad perspective of CT persisted and impacted how she saw CT practices in the lessons she designed and implemented. She also maintained a focus on safety and conduct as she edited lesson plans to prevent her students from engaging with dangerous materials or misbehaving. While some aspects of her social context had changed—such as an increase in the availability of technology in her classroom—Anna still had little autonomy over the science curriculum and could not make great changes to the county-provided lessons. Moreover, she believed that the existing curriculum *already* engaged students in some CT practices and that integrating more complex practices like programming was difficult due to time constraints and her lack of confidence with coding.

Overall, Anna's case is an illustration that the factors that led to an appropriation of labels during the STIG^{CT} can influence subsequent appropriation of CT. Particularly, the combination of a broad perspective of CT and a rigid curriculum that allowed little change seemed to contribute to Anna implementing a new set of lessons that, while described through CT language, resembled typical science instruction.

Anna in the STIG^{CT}

During her participation in the STIG^{CT}, Anna's conceptual understanding of CT was characterized by a broad perspective of CT practices that included typical science practices. Her personal characteristics included enthusiasm about CT coupled with concerns about classroom control that prevented her from giving students too much autonomy. Her social context was defined by a rigid curriculum and mentor that discouraged innovation.

Anna's final lesson engaged students in learning about which items can be "reused, reduced or recycled" and how to sort them. It follows a three-part template called "Launch, Model, Explore". In the Launch portion, Anna showed students a can of Coke and a piece of art made of recycled Coke cans, asking students to think about how the cans had been reused. In the Model section, Anna sorted different items into recyclable and non-recyclable, explaining her thought process as she made decisions, *modeling* the process students should follow. Next, in the Explore section, students were paired-up and tasked with sorting a group of new items into recyclable and non-recyclable bins. As a closing activity, the class played a game together on the classroom projector. In the game, the player helps an animal cartoon character pick items off a conveyor belt and put them in a recycling bin. Players get points for recycling correct items and points deducted for attempting to recycle non-recyclable materials. In Anna's lesson, the students played together as a class by raising their hands whenever they saw an item that should be recycled, and having Anna make the move on the projector. Finally, Anna led a discussion on which materials could be recycled and which ones could not.

Broad perspective of CT

In her lesson reflection, Anna saw her lesson engaging students in three different CT practices. She explained that the conversation during the Launch portion made students think about how a Coke can become art, engaging them in the CT practice of *Breaking down problems into smaller parts*:

> *I asked questions like: "What do you think this is? What resources is this made out of? How do you think this person made it into a flower? Would this be reduce, reuse, or recycle? Why?" This began breaking up the problem into smaller parts to see the before and after of what we can do with recycling. This CT skill is used throughout [the lesson] where students have to determine what the object is and what we can do as humans to help the Earth.*

The second CT practice present in the lesson was what Anna described as an "algorithm step-by-step system relationship tree" most closely aligned with the practice of *Creating step-by-step instructions to solve a problem*. However, the lesson reflection shows that it was *Anna* who created the steps for students to follow:

> *I saw some students struggle to identify which category it went into so I wrote questions students can ask themselves under "recycle" and "reduce" to help them determine if the object can be recycled or reduced.*

Finally, Anna tentatively suggested that her lesson had also engaged students in *Using computational simulations* through the recycling game: "I used simulations (or I think) in my closure where, as a class, we played Litter Critters" (Written reflection). This lesson, which Anna herself described as "teacher-centered," resembled traditional science learning where students learned about a science concept, practiced applying it in an activity, and had discussions to cement their understanding. However, this lesson did not introduce students to computing concepts and did not engage students in learning science *through* CT. The three practices that Anna identified in her lesson fit with a broad interpretation of CT—one that did not emphasize connections to computing.

First, the description of the Launch portion of the lesson as engaging students in *Breaking down problems into smaller parts* neglects that those parts are not meant to be carried out by a computational agent. In other words, both the problem and the parts of the solution have no connection to computing.

The second practice Anna identified, *Creating step-by-step instructions to solve a problem,* was arguably present in the lesson. However, it was clear that *students* did not get to engage in that practice. Instead, Anna created the key questions for her students to ask. While students may begin to understand the importance of well-sequenced instructions by following them, the goal of CT integration is that students get used to *creating* those instructions, especially when they are given to a computational agent.

Finally, Anna explains that the online game the class played could be interpreted as a simulation, as it "simulates" a real situation where a person has to make decisions on which items to recycle. However, this broad interpretation of the word “simulation” dilutes the benefit of students engaging with computational representations of scientific phenomena that allow them to create scenarios, test hypotheses, and visualize unobservable events. Anna’s description of the game does not indicate any of these affordances were present.

Classroom control

Anna shared concerns about student conduct when teaching science, particularly when integrating activities unfamiliar to students. When sharing her experience teaching the lesson she designed, Anna recognized that her lesson was more “teacher-centered” than she would have liked, but justified her decisions on issues of student conduct:

Anna: *I also did a recycling activity with [my students] online where they had to sort through recycling. Of course it was teacher-centered, but my kids got very loud and very obnoxious and it was really hard to bring them down.*

Interviewer: *On recycling?*

Anna: *Believe it or not, yes. They jumped out of their seats screaming at everything because they're like, "No, it's not recycled!"*

Resident: *It's engaging.*

Anna: *See, my kids take it too far to the point where it's dangerous. My kid's standing on a chair and it's like, "You need to get down."*

It seemed like, in Anna’s perspective, some of the CT activities suggested in the STIG^{CT} would require a certain level of student autonomy, which would be hard to implement in a class of very energetic students.

School-level obstacles

Anna participated in the STIG^{CT} without her mentor, who she described as an “old school” teacher who would be less open to integrating CT into science than others. In a written reflection, she shared that a problem with CT integration was that “mentors don’t use CT within lesson or don’t know they are using CT.”

Additionally, she often talked about needing ideas to integrate CT without the need for technology. In a written reflection, she explained:

> *I could definitely see myself implementing data into my lesson seeds. My class is low tech so that’s something I would have to work around.*

In a focus group, she elaborated: “we don't have technology whatsoever in my classroom.” The lesson she designed, however, listed a projector, laptops, and WiFi as technology materials—so she likely meant her classroom did not have any robots or programmable devices like the ones showed in the STIG^{CT}.

Overall, Anna’s appropriation of CT during the STIG^{CT} was greatly impacted by her broad conceptualization of CT and the obstacles towards integration she faced. This type of appropriation seemed to continue in the year after the PD.

CT Integration after the STIG

After graduating from the program, Anna went on to teach 5th grade Math, Science and Social Studies at a different school. Although she was now a full-time teacher in a different school and teaching the oldest Elementary grade instead of the youngest, her reflections around integrating CT in this new context echoed her experience as a resident in the STIG^{CT}.

Consistent with the final lesson that Anna designed in the STIG^{CT}, the two CT-integrated lessons she implemented as a full-time teacher closely resembled typical science instruction while Anna described them as engaging students in CT. The first lesson was part of a school-wide project where students were tasked with using different crafting items to create a small vehicle that could carry an egg and protect it from breaking in a collision. Students used a pre-selected list of materials and tested their “cars” in a make-shift ramp made of a cardboard piece angled on a low bookshelf. Students tried different designs in groups and some children had discussions around friction and velocity.

The second lesson involved mixing a list of pre-selected substances and taking qualitative notes of physical and chemical reactions on a graphic organizer provided by the county curriculum. After testing each substance, students had to deduce the nature of a "mystery substance" by testing how it reacted to different substances and comparing those reactions to their notes.

Anna's integration of CT was characterized by two themes: a propensity to identify CT practices in all activities (even those without a computational component) and difficulty circumventing obstacles that prevented her from designing more ambitious CT lesson designs. Below, I describe these themes and how they impacted Anna's integration of CT after her participation in the STIG^{CT}.

CT is everywhere

When discussing CT practices present in her lessons, Anna was quick to identify multiple activities as engaging students in CT—a perspective she had already shown when reflecting on her STIG^{CT} final lesson. In the year following the PD, Anna described the two instances of CT in her classroom as being "already embedded" in the curriculum, so she didn't have to integrate it. This lack of *purposeful* integration of CT was best illustrated by Anna's descriptions of CT as something that was inadvertently present in lessons—not intentionally integrated. For example, in the first interview, Anna shared that she had "been doing CT without even realizing that I have been." This stealthy form of CT also applied to students—Anna did not communicate to children that they were engaging in CT but noted "they are doing it—they are just not aware of it."

The lessons she described as instances of CT were, in fact, designed and provided by her county—Anna only made small tweaks to them that were unrelated to CT (such as editing the list of materials that included bleach for safer alternatives.) One of the lessons was part of a school-wide project where students were tasked with using different crafting items to create a small vehicle that could carry an egg and protect it from breaking in a collision. Students used a pre-selected list of materials and tested their "cars" in a make-shift ramp made of a cardboard piece angled on a low bookshelf. Students tried different designs in groups and some children had discussions around friction and velocity.

Discussing this car design lesson, she saw these activities as engaging students in CT:

> *Interviewer:* *So, would you say that this lesson engaged children in CT?*
>
> *Anna:* *Yeah, definitely. Um, if you think about it, like, CT is about breaking down the problem. It's also about designing, evaluating, and I think the kids definitely hit on all of those.*

Although Anna conceded that she had forgotten the names of the practices we shared in our CT framework, she described them in her own words. In the car design lesson, students had engaged in CT when they had to think of every part of the car (*Breaking down problems into smaller parts*) and when they had tested their cars (*Test, adjust to improve, retest, readjust to improve*.)

The second CT-integrated lesson Anna taught involved mixing a list of pre-selected substances and taking qualitative notes of physical and chemical reactions on a graphic organizer provided by the county curriculum. After testing each substance, students had to deduce the nature of a "mystery substance" by testing how it reacted to different substances and comparing those reactions to their notes.

Once again, Anna suggested that this lesson had engaged students in CT by asking them to break down a problem (what is the mystery substance) into smaller parts and encouraging them to rule out different substances based on their notes. It is unclear which CT practice this latter portion of the lesson represented, but Anna identified it as a part of the CT present in the lesson.

However, an analysis of the lesson shows that, similarly to her experience in the STIG^{CT}, Anna's CT integration is best described as appropriating CT labels. The two lessons she described resembled typical science lessons. In fact, they *were* unedited county science lessons.[2] They neither introduced students to computing nor did so in a way that supported their scientific learning.

Anna's broad perspective of CT seemed greatly impact how she planned and implemented CT-integrated science lessons. On the planning phase, Anna did not feel like she needed to edit her plans—the lessons already had CT "embedded" in them. Moreover, she explained that she had integrated CT without planning for it at all ("without even realizing it.")

When implementing these lessons, Anna's broad perspective of CT also played a role in how she interacted with students and the thought processes she encouraged in them. For example, after noticing that two student groups had not yet considered how the wheels in their car design would turn, she stopped the whole class, engaged them in brainstorming designs to ensure wheel-turning, and then allowed students to continue. Considering that these design practices fit within her broad perspective of CT, Anna saw this pedagogical move of encouraging brainstorming as part of engaging students in CT.

Obstacles to integration

In addition to her propensity to see CT everywhere in lessons, Anna's integration of CT was marked by different obstacles that deterred her from planning more ambitious lessons that involved more complex CT practices like programming. Specifically, Anna faced a rigid curriculum and time constraints that disallowed innovation; had a lack of confidence with programming practices that prevented her from integrating coding activities; and held concerns about classroom safety and control that discouraged her from giving students too much student autonomy.

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[2] While it is not impossible that county-designed lessons engage students in CT, it is quite unlikely, given that there are many initiatives aimed at *adapting* existing curricula to integrate CT. If they already had CT embedded in them, we wouldn't need to adapt them, and those initiatives wouldn't exist or be funded.

Curriculum constraints. Anna worked in a county and school that prescribed the science lessons that educators needed to teach at each term. The county divided the academic year into “marking periods” and decided what should be taught on each period. For each of these periods, the county would send teachers the necessary materials for each lesson. The only modifications that Anna could make had to fall *within* the given plan—she did not have the autonomy to decide to teach the same content through different activities. The level of control that the county had over her lessons was illustrated during one of the interviews, where Anna lamented that she would not be able to teach the “mystery substance” lesson in the following year:

> *I'm actually really upset because we saw—or they [the county] released our science curriculum and we're not doing this [lesson] next year.*

When discussing potential future implementations of CT, Anna also explained that innovative activities, like designing animations on Scratch, would need to happen *after* meeting the requirements of the marking periods. She did not foresee many opportunities to integrate those activities:

> *But again, I don't completely understand Scratch and it would take the kids time to also figure it out, which generally—I don't have the time for a no-marking period, unfortunately.*

These time and curricular obstacles Anna encountered resembled her experience in the STIG^{CT}, where she worked with a mentor who was not knowledgeable about CT and did not allow room for much classroom experimentation.

Lack of Confidence with Programming. As the quote above indicates, Anna did not feel comfortable with programming practices or with coding platforms like Scratch. Despite learning about these tools in her science methods course as a resident, during the STIG^{CT}, and during professional development provided by her county, she still had low confidence in her ability to understand and implement Scratch:

So, I remember we did something on Scratch during our CT and also our [county] class. I never completely mastered it, but all of the kids that I teach are gifted and talented, so I feel like they would be able to figure it out or teach me even.

Unfortunately, this lack of confidence prevented her from implementing coding activities—even when students showed interest in learning programming and when she felt that students would benefit from engaging in those practices:

> *Anna:* I feel like my students could display their knowledge by creating a Scratch. And I feel like that would have been very engaging for them. I actually had one student who just wrote codes on the side of his paper, because he liked to and I thought that was interesting, but I just kind of ignored it. So, I feel like in general, like the levels of my kids that I had last year, it would have definitely worked out.
>
> *Interviewer:* Can you tell me some of the obstacles or some of the things that have made you have to ignore it or not be able to take on that activity?
>
> *Anna:* Yeah, so I would say definitely—I didn't completely understand it.

Anna was optimistic that with more time to practice working with Scratch, she would "eventually learn" but she did not share any specific plans to integrate programming into her science lessons in the near future—particularly within the curricular constraints explained above.

Classroom Safety and Control. As she did during the STIG^{CT}, Anna maintained concerns about classroom safety and control that discouraged her from giving students too much student autonomy during activities. While the county provided Anna with materials and lesson plans, she often edited these for safety reasons. For example, in the "mystery substance" lesson, she removed bleach as a test substance because she felt it would be unsafe for students to work with it. In the car design lesson, when she saw students breaking wooden rods in half to make two smaller rods, she intervened:

> *But we also had like these like up wooden rods and the kids were like breaking that in half too. And I was like, Okay, this is kind of unsafe, we need to do something about it. […] once I saw one kid [breaking the rods], I was like, "all right, we're done here. We're not going to do this." Um, so I guess after that, it made me kind of take a step back and think of—okay, well, we're going to give them scissors and if they need anything broken, I made it like a new rule of "you need to let me do it so you guys don't get hurt." Obviously, we don't want me hurt either but—less liability.*

Another pedagogical decision Anna made was to add a pre-lesson clean-up demo for her second section after the students in the first period had left a mess. She saw tensions between allowing students to engage with the materials of the lesson and keeping a tidy classroom:

> *that's one thing that I kind of had to like reinforce and like—you always want to be hands on, but at the same time, like they need to be responsible.*

These concerns about student responsibility also prevented Anna from planning to use technology in the classroom. Specifically, she shared that her school had access to Chromebooks, but the logistics of getting enough devices for her large class and concerns around breaking the devices discouraged her from using them:

> *And also (laughing) my kids are very privileged, I want to call it, so they don't really take care of things that well. So, that kind of prevents me from using things as well. Even though I went over the basics 101, this is the way you handle a Chromebook, this is the way that you hold one, once you have it in your hand, you pick a spot in the room, you do your work there and you do not move until I say to put it away (laughing). Yeah, I just feel like they're not very careful with it, so that kind of, I mean I had to put a couple through repairs just because they're not very responsible with it.*

These concerns about keeping devices safe and students from misbehaving dissuaded Anna from using technology in her classroom and, instead, she opted for materials that would require less supervision. Anna's social context, plagued with multiple obstacles to integration, did not support her ability to successfully integrate CT into her science instruction.

Case Conclusions

Overall, Anna maintained her level of appropriation from the STIG^{CT}. During and after the PD, she appropriated CT labels, describing typical science lessons with language from the CT framework. In the year following the STIG^{CT}, Anna's planning and implementation of CT-integrated science lessons was influenced by her generalized view of CT practices and several integration obstacles. Her broad perspective of CT did not encourage purposeful CT integration—she already saw CT in the curriculum. Moreover, her lack of autonomy over the curriculum, her concerns over students' safety and responsibility with devices, and her lack of confidence with coding discouraged her from planning lessons that integrated other CT practices like programming.

This case seems to support Grossman et al.'s (1999) contention that knowledge, personal characteristics, and the social context of learning exercise an important influence on appropriation. It particularly supports the close relationship that the framework suggests between conceptual understanding and appropriation level. In this case, a broad view of CT that conflates the term with other typical practices found in a science classroom resulted in a passive approach to CT integration. Since CT is so broad that it is *already* embedded in the curriculum, there was no necessity for purposeful planning for integration. Additionally, the presence of personal characteristics like a lack of confidence with programming and social context factors like curricular constraints did not encourage integration of more CT practices or more ambitious lesson plans. Anna's case, then, should be considered an important example of how appropriation can remain at a low level if conceptual understanding is not addressed properly during PD.

Bridget: Supporting CT Evolution

Bridget's case shows how a teacher who had appropriated CT by integrating programming activities continued to do so in a school environment that replicated the level of support in planning and implementing CT-integrated lessons the STIG^{CT} had provided. Bridget participated as a returning resident in the STIG^{CT}, meaning that she had participated as a resident in the previous year, but was now coming back as a first-year full-time 4th grade teacher. Bridget's participation in the STIG^{CT} as a returning resident was marked by enthusiasm, fearlessness in integrating programming, technology availability, and support from her former mentor. She had appropriated CT as Programming as an Extension.

In year following participation, despite a few changes to her teaching position, Bridget integrated CT in similar ways. She integrated more programming science activities and aimed to integrate CT in lessons in other subjects like social studies and math. Again, she had technology available in her school and support from peers, which she claimed were essential to her CT integration.

Bridget in the STIG^{CT}

Bridget was the only teacher participating from her school, but her former mentor, who also taught 4th grade, was also participating in the STIG^{CT} as a returning mentor. The two often sat together and co-designed lessons during sessions and seemed to maintain a productive relationship. Bridget consistently tried to refine her conceptual understanding of CT by asking questions to researchers in her written reflections and interactions. Her personal characteristics included an enthusiasm for integrating CT into science lessons and a high level of comfort with technology in the classroom. Bridget also seemed to work in an environment supportive of CT integration—her school had devices like Makey-Makeys available, and her administration encouraged teachers to use these tools.

Bridget's final lesson consisted of a multi-day series of activities for students to learn about electric circuits and practice creating them. The lesson started with Bridget introducing how to make "paper circuits" and explaining how to make a simple switch. Then, in pairs, children followed a series of video guides to make paper circuits using aluminum foil, paper, and copper wire. After completing their circuits, students used Makey-Makeys—an electronic invention kit that uses a circuit board, alligator clips, and a USB cable to connect everyday objects to computer keys—to test them. During this testing process, students had to "troubleshoot" their circuits, going over a list of four possible reasons that circuits may malfunction which Bridget had provided in a worksheet. Once their circuits were working, students went on Scratch, connected their circuits to the computer via USB, and began programming the circuit to make a sound when the switch was turned on. Bridget provided a printout with instructions, including the two blocks that students needed to add to their program. Bridget's appropriation of CT during the STIG^{CT} is best described as Programming as an Extension and was characterized by three themes. First, Bridget demonstrated a perspective of CT as a method for learning content, echoing the conceptualization of CT that researchers put forward in the STIG^{CT}. This perspective impacted how she co-designed lessons, her interactions with researchers, and her reflections on the implemented lesson. Second, Bridget showed a fearless approach to innovation and experimentation in the classroom. She did not back out from trying out new technologies, was optimistic about her students' ability to learn science through CT, and was enthusiastic about implementing the lessons she co-designed in the PD. Third, Bridget's CT perspective and attitude towards classroom innovation were encouraged by a school context with available technology and administrative support that promoted STEM learning and flexibility.

CT as a method for learning

In her reflections, Bridget was inquisitive about the pedagogical nature of CT, pondering about the differences between students creating algorithms with and without a computer, asking researchers about the design of STIG^{CT} activities that teachers engaged in, and requesting assistance introducing CT to students with little background knowledge. For example, after the second STIG^{CT} session, she wrote:

> *I would like to learn more about creating algorithms both with and without the computer. How do you create the "templates" on Excel or Scratch that you make for us to build off of?(Written Reflection)*

She also described her lesson design process as starting with a learning objective and then exploring ways to teach that content "through*"* CT. This idea of learning science *through* CT is a nuanced and important conception that the researchers tried to communicate often. The fact that Bridget described the relationship between CT and disciplinary content as the researchers did suggests a good level of conceptual understanding of CT. However, this conceptualization was not clearly materialized in her final lesson where CT was used as an assessment of scientific learning instead.

In reflecting on her lesson implementation, Bridget continued to refine her understanding of CT and how it supports science learning. While she identified her lesson as engaging students in multiple CT practices, she also saw opportunities to strengthen those CT activities in the future. For example, she explained that the circuit-making portion of the class had engaged students in CT by teaching them "how to follow specific step-by-step instructions" and forced them to work to identify problems in their circuits and make necessary adjustments. She valued that type of productive struggle and thought that she could have implemented the programming activity in a way that encouraged a similar process:

> *"However, next time I might have my students attempt to code their circuits on Scratch with less guidance. I might use that part of the lesson as an opportunity to push their thinking and problem-solving skills to discover the correct code on their own. For students who need a scaffold, I could say that in their code they need to have an 'event' and then a 'sound'. This would provide them with some guidance and then they could troubleshoot from there with their partner."*

Bridget expanded on this idea of CT as a way of thinking related to problem-solving. In a focus group, she mentioned that teachers in her school talked about coding but "not really about CT—the thinking part of it." This statement can be interpreted as Bridget differentiating between activities more closely related to computer science and CT as a way of solving problems in multiple areas, including science.

Fearless innovation

During her STIG^{CT} participation, Bridget creative in coming up with ways to integrate CT and had no hesitation to try out new activities in her classroom. For example, when researchers showed her a website with science simulations, she immediately saw ways to implement them in her lessons, discussing with peers how to design activities that would challenge students and leverage the affordances of those simulations.

During lesson design sessions, Bridget participated actively by suggesting activities, explaining science concepts to the group, and asking questions to researchers about how to enhance CT integration.

When considering using a simulation on circuits, she saw the role of the tool as a way for students to test and cement their understanding *after* they've learned how circuits work.

With her former mentor, she also often tried to add further engagement with the simulation to her lesson. For example, she suggested adding an activity where students predict the light intensity if more batteries are added to the circuit, record those predictions on a graphic organized, and then test those predictions through the simulation. She also briefly mentioned the possibility of using micro:bits to collect data from real circuits in the future.

In the last design session of the STIG^{CT}, she discussed with a researcher how, if her students developed some background knowledge around coding, they could discuss how the simulation is programmed and the models that make it work. This suggestion demonstrated that Bridget had high expectations of her students and was not afraid to bring new and complex discussions—such as the mechanisms of computational simulations—into her classroom.

Increasingly supportive environment

Bridget described her school as a STEM school where they "have the robots and the tech and stuff." She explained that teachers do different coding activities with their students, but that she's the only one who talks about CT, a concept that she's brought up with peers since her participation in the STIG^{CT}. While she talked positively about her lesson involving Makey-makeys, she was most excited about the opportunities for CT integration in the year following the STIG^{CT}:

> *Bridget:* *So next year, I really want to try micro:bits.*
>
> *Interviewer:* *Do you have access to micro:bits?*
>
> *Bridget:* *I don't now, but my school was just—this year is the first year that we're a STEAM school. And, next year, because we're revamping everything—we're building this whole STEAM lab in my school, so I'm going to work with my STEAM coordinator to hopefully get some of that stuff, which will be really nice.*

Interviewer: *That's a great opportunity.*

Bridget: *Yeah. So next year will be really interesting. I'm really excited for it.*

However, not all aspects of Bridget’s social context were conducive of CT integration. In a focus group response, Bridget explained that her class was particularly raucous, and she often had to balance promoting open exploration with giving constrained instructions that would minimize behavioral issues. She preferred the former and believed that was best for students’ learning but conceded that “you kind of have to be realistic with what your class can handle.”

The fact that Bridget had a solid conceptual understanding of CT, personal characteristics that favored trying out new ideas in the classroom, and a social context supportive of innovation bring into question why she did not reach a conceptual level of CT appropriation. The explanation may lie on the *timing* of the design of the lesson she submitted.

During the second and third STIG^{CT} sessions, Bridget participated in co-design lesson sessions along her former mentor. They discussed how students could use a computational simulation to virtually create circuits; test questions about the relationship between batteries, volts, and light bulb brightness; and visualize electron movement. In the third STIG^{CT} session, Bridget even talked about implementing this lesson: “I’m excited. I want to do this tomorrow.”

However, Bridget’s final lesson did not include that computational simulation. Instead, her students created paper circuits using Makey-Makeys and then used Scratch programming to add sounds to those circuits. It is possible that Bridget designed and implemented her lesson after the *first* STIG^{CT} session, where the researchers showed participants how to use Scratch. As explained in the Programming as Extension profile, the example on that session entailed asking students to program a Scratch animation after they had learned about a scientific phenomenon. This idea parallels how Bridget integrated CT in her final lesson: she added a Scratch activity *after* students had learned how circuits work and made their own. Therefore, it is possible that the lesson Bridget implemented and submitted showed her integration of CT after the *first* session, and the ideas of integrating computational simulations developed *after* she had completed the assignment. This would explain the disconnect between her final lesson and the conceptualization of CT and lesson design ideas she shared during the rest of the STIG^{CT} sessions.

CT Integration after the STIG^{CT}

In the summer that followed her participation in the STIG^{CT}, Bridget started a Master's program in STEM Education and was moved from teaching math and science in 4th grade to teaching all subjects in 3rd grade. While Bridget called this transition "challenging," she felt supported by a "fantastic" team that helped her implement project-based learning in a STEM school. She also continued to be appreciative of the availability of technology at her school, where teachers had Makey-Makeys, Spheros, Dash robots and iPads available.

Overall, Bridget's integration of CT in the year after the STIG^{CT} was characterized by two themes. Namely, a school environment that allowed for flexibility and innovation and the development of a conceptualization of CT as a productive struggle. Each theme is best illustrated by one of the two different occasions where Bridget integrated CT into her instruction. Therefore, I describe each of her CT-integrated lessons within each theme below.

Support for Experimentation and Flexibility

Since Bridget continued to teach in the same school as she did when participating in the STIG^{CT}, the supportive environment she had available in the PD continued in the year that followed it. Her school had technology devices like Makey-Makeys, micro:bits, and Sphero robots available for teachers. Bridget was also part of the "STEM Committee" where teachers designed lessons and units to further STEM learning in their school.

Additionally, Bridget described that a certain barrier had been lifted in her second year at the school. She explained how the "craziness" of the first year as a full-time teacher had sent CT integration "to the backburner" but, having passed that initial frenzy, she felt more comfortable identifying and integrating

CT. Bridget’s enthusiasm, which was shared by her peers, seemed to be more focused on using robots than specifically thinking about the affordances of CT as a way of supporting scientific inquiry:

> *I love coding! (laughing) so we—and my teammates do as well—so we would try and kind of, find every and any excuse to incorporate coding. And kids love it, so they’re super engaged.*

Bridget’s first CT-integrated lesson illustrates one of these “excuses” to integrate coding on Sphero robots. Specifically, she integrated CT into a series of science lessons that took place after students had been learning about animal adaptation and ecosystems in the previous weeks. In this activity, Bridget started by giving students a few minutes to drive the robot around and “get it out of their system.” Then, she tasked students with “inventing” their own animal and deciding which characteristics it would have. After making their choices on a worksheet, children had to program a Sphero robot to mimic the characteristics of the animal they had created. For example, students could modify their code so that the Sphero would make a specific sound or move and behave like the made-up animal. As an assessment, Bridget helped students record a video explaining their animal, its adaptations, and how it was coded.

The support for flexibility and innovation in Bridget’s school also manifested in how she implemented this lesson. Instead of following a narrow lesson script, Bridget shared that she navigated the classroom freely, attending to student needs as they arose. This ability to roam was supported by her peers. For example, a teacher coordinator came to the classroom during the assessment portion and recorded students explaining their projects while Bridget asked questions. This help allowed Bridget to fully focus on assessing students’ understanding without worrying about the logistics of recording.

It seems like Bridget’s social context was conducive to integrating programming activities in her classroom. Interestingly, the Sphero lesson Bridget shared had some key similarities with the lesson she submitted for the STIG^{CT}. In both, the programming activity came *after* more traditional science learning. However, in this case, the programming was done through a physical robot, not Scratch. Moreover, Bridget did not see this activity as a programming learning activity only. In her perspective, programming robots had also helped students better understand the adaptations they were trying to mimic.

> *We wanted a way to make [the lesson] more engaging. And we knew that using Spheros and robots would do that instead of just simply teaching about adaptations. But we also thought it would be a great way to kind of explore what the adaptations actually mean—like they're kind of experiencing it as the animal instead of just kind of learning about it, if you know what I mean. Like, [the students] sitting there trying to get their Sphero to mimic their animal hunting… we were hoping that would make them better understand why that animal might need fast speed.*

This way of integrating CT, supported by her peers and the availability of technology at her school, seems to be a progression from her appropriation of CT during the STIG^{CT}, where the final lesson used programming as an extension relatively disconnected from the science topic. It also follows the ideas of learning science *through* CT that she shared in STIG^{CT} sessions but did not materialize in the final lesson submitted. The evolution of Bridget's conceptualization of CT is further developed in the second themed that characterized her integration of CT.

CT as Productive Struggle

During the STIG^{CT}, Bridget had already started to develop a conceptualization of CT as a generalized problem-solving strategy—one that could be applied to different problems, not just science investigations. Her integration of CT after the STIG^{CT} showed a further development of that perspective leading to conceptualizing CT as a type of productive struggle that encourages systematicity, perseverance, and reflection. This conceptualization of CT became apparent when Bridget implemented her Sphero lesson and tried to balance supporting her students with the goal of engaging them in a productive struggle:

> *…there were also some groups that were not as confident, and they were calling me over more frequently because they did not know [how to code it] and they wanted me to tell them what the right code was. Like, how did I do that? Is this the right way? And I was like, "try it and see if it works. If [the code] doesn't work, then we know that there is an error in there somewhere and we have to find it." And so, I was trying*

> *to get them to kind of explore it on their own and troubleshoot it on their own instead of me just telling them. I think I kept doing that enough that they finally knew that I was not going to give them the answer. They had to figure it out on their own and that caused some frustration for a few of my students. So, I had to scaffold that a little bit.*

Bridget saw this process, which she described as engaging in CT, as beneficial for learning. She wanted to replicate it in other lessons and designed a second CT-integrated lesson that illustrated her conceptualization of CT as a productive struggle.

In this case, Bridget incorporated CT into a project-based learning unit exploring the Egyptian ancient civilization. This unit crossed multiple subjects including Social Studies, Math, and Science. Groups of students were tasked with designing and building an irrigation system using a limited budget of fake money for construction materials like tape, foil paper, twist ties, rubber bands, and clay. As part of their learning, students had to test the system, fix any issues by buying additional materials with remaining funds, and “reflect on the process.”

The design of this lesson was, as Bridget explains, heavily impacted by the first attempt to use Sphero robots. Bridget explained that her team wanted to plan the lesson so that it would promote the type of productive “frustration” that kids had encountered when programming robots for the first time:

> *There's academic frustration. And then there's a frustration you see with children when they're playing a game where it's like ‘Oh no,’ but then you keep playing that game. Like, you know you just got to do something else. And so, we [the teaching team] were hoping [the lesson] would be more of that. Instead of an academic frustration where then they just kind of quit and realized like, ‘oh, this is hard. I can't do it.’ And it was more of the game frustration. We saw a frustration [in the Sphero lesson] that they wanted to work through because they really bought into the end goal.*

With this goal of creating a lesson that provided opportunities for a productive type of frustration, Bridget and her teacher partners purposefully designed class materials and a lesson with constraints that forced students to make compromises in the design of an irrigation system. But the planned integration of CT in this instance focused more on practices that developed a perseverance disposition than on using computing as a way to engage with disciplinary content. The two CT practices that Bridget identified in this lesson, “decomposition and troubleshooting” did not retain a computational perspective, but instead were meant to serve as ways of provoking the desired type of “frustration.” In fact, Bridget said that, during the planning of this lesson, she had not brought up the term CT to her teacher partners.

Moreover, Bridget recognized that the CT in this lesson, conceptualized as engaging in a productive struggle, was a new experience for all her students that challenged the status quo of the classroom and reorganized conceptions of success in her students. She found this realignment beneficial for students who were traditionally successful and those who normally did not see themselves as top of the class:

> *I had the gifted cluster in my class last year, and so some of my gifted students—it was only a couple of them—but it was interesting to see them in this role. Because they are high-flyers in the class academically, and so they are used to knowing how to do it and kind of being the one in the class that knows how to do it and how to come easily. And so, then we started this [CT lesson], and this is just so different than anything we’ve ever done, and to see some of them struggle, they were getting kind of frustrated with themselves, I think they expected it to come easier. And then some of my other students who are not gifted, are not as high academically, were kind of excelling and it was like a weird flip-flop role situation. And I think it was good for them to be put in that spot and they kind of saw that these other people have value, which that was unexpected, I did not even know that that would happen. But that was a good outcome for it.*

However, Bridget shared that she never mentioned to the students that they were engaging in CT. In her view, the experience of engaging in CT was a prerequisite for learning what CT is—students needed a tangible experience that they could attach the term “CT” to. Her statements reflect a perspective of CT as a broad problem-solving strategy that encourages perseverance and troubleshooting even in students who are not typically challenged. This perspective seems to have evolved from seeing students directly engage in computing activities yet is not necessarily attached to leveraging computing concepts.

Case Conclusions

Bridget’s integration of CT in the classroom as a first-year teacher seemed to build from the appropriation of CT she demonstrated in the STIG^{CT}. While her STIG^{CT} lesson only used programming as a way to introduce computing concepts with little connection to the scientific topic (how circuits work), the Sphero robot lesson showed a stronger connection between the programming activity and the science content. Specifically, Bridget saw the programming of animal behaviors as a way for students to better understand those behaviors by trying to mimic them.

The second lesson, on the other hand, did not involve any programming, but instead tried to replicate the same type of “productive furstration” that students had engaged in when coding while working on different activities. This lesson demonstrates a slight variation from thinking of CT as aligned with computing devices to conceptualizing it as a set of mindsets or generalizable thinking practices.

The way she planned and implemented these lessons was influenced by her perspective of CT as a general problem-solving strategy and an environment supportive of innovation. Particularly, the relationship between Bridget’s conceptualization of CT and computing is noteworthy. The way Bridget saw CT after the STIG^{CT} seemed to come out of observing how students engaged in computing activities, specifically programming. The way Bridget tried to integrate CT after those activities, however, was not connected to computing. Instead, she tried to replicate the type of *thinking* necessary to program a robot to approach a different problem—the construction of an irrigation model. The argument that the type of thinking necessary in computing can be a productive approach to other problems is indeed in line some proponents of CT in schools (Wing, 2006). It does not, however, necessarily match the specified goals of the STIG^{CT} for CT appropriation. A generalized view of CT may lead to implementations that do not introduce students to computing concepts or leverage computing to learn science. Bridget’s view, for example, seemed to focus on the cognitive and dispositional aspects of CT, not the computational concepts that can be leveraged for scientific investigation.

Nevertheless, Bridget seemed to have enough flexibility and support to adopt multiple ways of CT integration: (a) computing activities that clearly introduce students to computing and could help students learn about scientific phenomena and (b) non-science lessons where the types of productive struggle necessary to complete programming activities are promoted to solve other problems. Therefore, her appropriation of CT seemed to evolve and expand after the STIG^{CT}. Importantly, Bridget's case shows how factors like technology availability, opportunities to co-design lessons, and a community of teachers that support each other can encourage appropriations of CT that involve computational devices, introduce students to computing, and support scientific learning. It also highlights the role of conceptual understanding and how a teachers' conceptualization of CT impacts the aspects of CT that she identifies and tries to encourage in her students.

Cassie: Gradually Improving on Examples

Cassie is an experienced 2nd grade teacher at Marshmallow Elementary and she participated in the STIG^{CT} as a new teacher mentor. She had a Talented and Gifted (TAG) classroom and taught all academic subjects, including science. Overall, Cassie's participation in the STIG^{CT} was enthusiastic about CT integration but tinted by a sense of novelty and hesitancy about the most complex forms of CT—like programming. She integrated CT by engaging students in a computational simulation, which she described as the simplest way to start and one that would require already available resources, like Chromebooks.

After her participation in the STIG^{CT}, Cassie's integration of CT remained the same—almost identical. In the year following the PD, Cassie integrated the same lesson she had co-designed with her mentee and another activity the STIG^{CT} staff had modeled. However, she made small—yet important—modifications to those lessons that allowed her to see some areas for improvement and gave her ideas on how to support student learning with the simulation in the future.

Cassie in the STIG^{CT}

Cassie's appropriation of CT, best fitting the Simulation for Investigation and Visualization profile, was characterized by an act of balancing needs. Throughout her participation in the STIG^{CT}, Cassie negotiated demands from curriculum, the PD requirements, and her own beliefs and abilities. Her final lesson showed a compromise between meeting the curricular demands of her school, integrating CT in a way that was consistent with the STIG^{CT} requirements, working within her level of comfort with CT practices, and attending to developmental appropriateness.

Balancing Needs

Cassie was committed to learning about CT and integrating it in her lesson. During lesson co-design sessions, she often pushed her design team to add an activity that would engage students in additional CT practices. Her often aimed to improve her conceptual understanding of CT: she asked researchers about the difference between videos and simulations, whether programming should be a part of the lesson objective by itself, and whether students should write steps for an algorithm *while* they create and test it or *after* they have finalized them. These questions seemed to also serve as a "check" to ensure that her lesson appropriately met the requirements of the PD by integrating CT practices as the researchers had defined it.

Yet, as a new teacher in the PD, Cassie occasionally shared feeling unconfident about her mastery of CT. For example, she asked for simulations for "clueless in CT teachers" in a written reflection and shared her struggle with understanding Scratch and Code-a-pillar robots during co-design sessions—describing herself as "not too tech savvy to begin with."

Cassie also showed a concern around developmental appropriateness. In focus groups and lesson design sessions, she talked about how she could only adapt certain tools that she thought were appropriate for her 2nd grade students. For example, she saw no room for the micro:bit in her science teaching:

> *this is probably beneficial in middle school or high school, but I cannot figure out a way where I would ever be able to fit that in with a second grade class.*

In the STIG^{CT}, Cassie seemed to have a good level of companionship. She had a total of 11 peer participants who taught at Marshmallow Elementary (whether as full-time teachers or placed residents) including her own mentee who shared Cassie's commitment to integrating CT into her lesson. However, she often cited curriculum-based constraints to CT integration:

> *I do think from this [the STIG^{CT}], I can take science lessons more easily and identify parts that are CT. I don't think our curriculum is naturally designed in that way. So, the problem is we have to take the lessons and adapt them. Which I think I'm more able to do now, but it's the typical problems. One is time, you know, and for a new teacher or someone with not much experience, that's difficult for them to do. And then two is just materials. So, I think I'm more aware of what CT is and how to better my lesson with it, but it's just— realistically, can I do that with what I'm given? You know?*

Cassie's final lesson plan showed a compromise between her commitment to integrating CT, her timid approach to integration due to a lack of confidence in her understanding of the practices, and her responsibility to work within the given curriculum. In fact, she described the design of her lesson, which involved using a simulation to visualize a phenomenon, as "the simplest way to jump off the boat."

The lesson was based on an existing lesson on the topic of states of matter. It began by showing students two water bottles: one frozen and one at room temperature. Students observed the bottles and talked to each other about differences they noticed. Then, in groups of three, students completed a "sorting" activity where they had to determine which state of matter change process (melting, freezing, condensation, or evaporation) was taking place in a set of scenarios. After this activity, Cassie provided students with a simulation on their Chromebook and an observation chart with three categories: "Heat, Normal, Cold." In this simulation, students were able to alter the temperature of a water container and see changes in molecules spacing and movement speed. Finally, as a group, the class shared their observations and consolidated their understanding of the relationship between molecule behavior and states of matter.

In her reflection, Cassie saw the lesson as a success, explaining how students had been engaged, enjoyed using the simulation, and—most importantly—had understood the relationship between the movement of molecules and states of matter. Cassie's case is an example of integrating CT by engaging students with a Simulation as a Visualization and Integration tool. Cassie's only modification to the way she typically taught this topic was the addition of the simulation—which she described as a low-barrier approach because it required little instructional change and the technology was already available to her students. Her approach to integration based on balancing needs (illustrated by her "jumping the boat" quote) continued after her participation in the PD.

CT Integration after the STIG^{CT}

After her participation in the STIG^{CT}, Cassie continued in her role as a 2nd grade TAG teacher at Marshmallow Elementary. She described her ability to integrate CT after her participation in the PD as "Probably not as much as I would like or would be beneficial to the students—I guess—but I did a couple lessons." The instances of integration she *did* implement were characterized by two themes. First, Cassie's lessons were replications of examples she had seen or designed in the STIG^{CT}, not new activities she came up with after the PD. Second, her planning and implementation process was limited to making small modifications on existing lessons, demonstrating an incremental approach to lesson design.

Replicating STIG^{CT} Examples

When describing her two instances of CT integration after the STIG^{CT}, Cassie explained that those lessons were heavily based on the examples she had seen during the PD:

> *really it was all the lessons that when I went to the [STIG^{CT}] trainings, I just basically copied exactly what we did at our trainings with you guys. I didn't really come up with anything on my own.*

In her first lesson, Cassie led her students through a birdwatching activity where they used the UrbanBirds website to download a worksheet, observed birds in the area of their outdoor classroom, and uploaded the data to the Citizen Science project. This activity was taken from the pre-participation workshop Cassie participated in as an incoming new teacher to the STIG^{CT}. In that workshop, researchers showed the UrbanBirds project to teachers and explained how students could use the website's activities to engage with data collection and analysis as instances of CT engagement. In her lesson, Cassie also showed students a visualization of migration patterns of Baltimore orioles and how those will likely morph in the future due to climate change—a simulation demonstrated in the same pre-participation workshop.

The second lesson was led by Cassie's intern and mentee, who had participated in the STIG^{CT}, and was exactly the same lesson that they had submitted as their final lesson plan. Students learned about states of matter and engaged with a computational simulation that showed the movement of molecules when heat was added or subtracted.

While these examples were taken directly from the STIG^{CT}, Cassie also shared that she had designed a third lesson but never got to implement it. Paired with another STIG^{CT} teacher and her mentee, they created a plan where students would explore the concept of animals and their habitats by using a Code-a-Pillar, a device that the STIG^{CT} had made available for teachers to borrow. In this lesson, students would create a grid structure to design a habitat for an animal, represented by the robot, and program their Code-a-Pillar to navigate that habitat looking for food and avoid predators. When asked about the reasons that prevented her from implementing the lesson, Cassie referred to a lack of resources. While the staff from the STIG^{CT} had extended the ability to borrow computational tools to teachers through a "CT library," Cassie explained that the added burden of having to travel to the university to pick up and drop off the Code-a-Pillar was significant enough to prevent her from implementing the lesson.

These lessons show that Cassie was committed to integrating CT into her instruction but limited her integration to examples she had seen in the STIG^{CT}. At the same time, the instances of CT integration she shared were only possible because they worked within the existing school conditions and leveraged available resources. For example, Cassie explained her decision to teach the bird data lesson as an opportunity to use the new outdoor classroom the school had installed—even if it was not aimed to support a specific curricular unit. Moreover, she shared that the state of matter simulations lesson had helped meet the requirements towards an “Excellence in Gifted and Talented Education (EGATE) Award,” since integrating CT into science was seen as a desirable innovation in education. On the other hand, when an opportunity to expand on those examples appeared, the logistical constraints of acquiring the required technology (Code-a-Pillars) prevented her from implementing that opportunity.

Cassie’s adherence to the STIG^{CT} lessons shows the importance of PD in two different ways. First, it demonstrates that the examples researchers show during PD should be carefully planned, as they may be directly replicated by teachers in the classroom. This replication dynamic was also apparent in the teachers who integrated programming activities based on the Scratch demo in the STIG^{CT}. Second, Cassie’s experience suggests that PD should aim to equip teachers with the ability to expand and continue their learning *after* graduation from the program. If teachers leave the PD with little confidence to step away from the examples provided and little support (like material resources) to experiment in the classroom, it is unlikely that they will create new ways of integrating CT into their instruction. Yet, Cassie’s eagerness to design a new lesson using Code-a-Pillars suggests that there are integration opportunities going unrealized due to school-level constrains and resource unavailability.

Incremental Refinement

While Cassie replicated the lessons she learned about in the STIG^{CT}, she did not simply copy the activities without any reflection or modification. Her case is not one of *inaction*—she used the available lessons as starting points and made small edits within the constraints of her school environment.

Cassie’s approach to lesson design was one of incremental refinement, using first an existing lesson to add CT during the STIG^{CT} and then make small modifications after reflecting on that experience for the following year. For example, she added a “sorting” activity—seen on a teaching resources website Cassie frequently uses—as a preamble to engaging with a computational simulation. This activity provided more practice for students to solidify their understanding of each state of matter before visualizing them on the computer. She also created exit tickets for the bird data lesson to quickly assess how students were comprehending science content.

When reflecting on her integration of CT, Cassie saw the flaws on her lessons but was confident that a few modifications could significantly improve their impact. Nonetheless, she still saw her integration as successful, and highlighted that, in both lessons, students were engaged and enjoying the activities. She also mentioned that the simulation had provided a unique affordance related to science learning: the ability for students to see something invisible—the movement of molecules. She compared that effective visualization to the difficulty of teaching about diminutive particles using real substances like ice or water as examples.

As Cassie reflected on these lessons, she came up with ideas to counter the flaws she identified, albeit still limited to small edits—she did not venture into ambitious redesigns of how students engaged in CT. When reflecting on the computational simulation lesson, Cassie's initial hope that students would deduce relationships between increases in temperature and increases in molecule movement proved to be overly optimistic. While students seemed to be engaged in the activity, the individual assessments Cassie had created casted doubt on how well students were grasping the content:

> *it's one of those things where I kind of thought they understood when we were doing it as a group, but then when I gave them their worksheet and they were expected to do it independently, I kind of saw like they do not understand this as much as I think they do.*

This finding was surprising to her, especially considering that in her reflection of implementing this same lesson during the STIG^{CT} year, she had noted that students "were able to make generalizations about molecules and how they look different in solids, liquids, and gases using the simulation." Cassie explained that the difficulty in making this connection could stem from the freedom of exploration she had implemented in the simulation activity:

> *they [students] were just kind of like fumbling around on the [simulation] website, and like [noticing] 'look at these things moving around, this is really neat, and if I*

> *change it, they move around differently.' So, I think there would have to be some type of better follow-up from that [engagement].*

In her opinion, the "better follow-up" could entail providing more structure to student observations during the simulation activity, such as a worksheet where students notice molecule behavior changes on high, medium, and low temperatures. This could help students organize their engagement with the simulation and help them see patterns in how molecules react to temperature changes.

Cassie's incremental approach was explained by her time and resources constraints that she shared above. Thinking of the future, Cassie remained doubtful of expanding CT integration, as the constraints that had stopped her from designing and implementing new lessons were likely to persist:

> *It seems like these types of lessons are not embedded in the curriculum. You really have to take the time and design them yourself. You know, if your colleagues are not on board with that, or even if you want to do it yourself, it's just time consuming to do that for every lesson.*

This approach to lesson design highlights the importance of supporting teachers to integrate CT *within their existing environments*. Cassie's case is one of a committed teacher who wants to integrate CT but can only do so if the lessons leverage the resources she has available or help meet other educational goals. Her experience demonstrates, again, that school-level factors can determine the extent of CT integration—regardless of a teachers' enthusiasm or commitment to the innovation.

Case Conclusions

After her participation in the STIG^{CT}, Cassie's appropriation of CT continued in a similar fashion. She replicated the same lesson she had designed during the PD and added another activity afforded by her school's new outdoor classroom. While she re-implemented these lessons, she also made small modifications and reflected on further refinements to make them more effective.

Overall, Cassie's case shows the tension between trying to bring an innovative pedagogical tool like CT into the classroom while navigating school-level constraints such as limited time to design lessons, curricular goals, and technology availability. Within this environment, Cassie was limited to making small edits to existing lessons and refining them incrementally—she was unable to implement more ambitious plans that required additional resources.

Her case provides more evidence that appropriation of CT is greatly impacted by the social context of teachers and the environment in which they are expected to integrate CT. Even when Cassie started to overcome the hesitancy around programming practices she shared in the STIG^{CT} by designing a Code-a-Pillar programming activity, the lack of resources in her school prevented her from taking that leap.

Dakota: Fighting for Innovation amidst Uniformity

Dakota's case is an example of a first-year teacher who, after showing a good understanding of CT in the STIG^{CT} and enthusiasm for integration, had to reduce her integration to small modifications of existing lessons in a new school that discouraged innovation. Dakota participated in the STIG^{CT} as a 4th grade resident with her mentor, who was an experienced teacher returning for a second year of STIG^{CT} participation. The pair was also accompanied by numerous colleagues from Marshmallow school, including Cassie. During the STIG^{CT}, Dakota often pushed her mentor and others to make their integrated activities more computational, questioned the boundaries of CT, and seemed to focus on what students would be learning from engaging on CT lessons.

After the STIG^{CT}, Dakota's integration of CT changed to meet the curricular demands of her new school—Strawberry Elementary. In this new year, she integrated CT by making small implementation modifications to the county's curriculum, as she had no power to change lesson plans. The small modifications entailed promoting the use of Excel for data collection and analysis while promoting data-based discussions among students. These changes in appropriation were largely due to changes in her context, including a new school with new teachers and a principal that promoted homogeneity in instruction.

Dakota in the STIG^{CT}

Dakota’s participation in the PD was characterized by an enterprising approach to CT integration that challenged traditional instruction ideas. Her conceptualization of CT was attached to engaging with computational devices and she showed enthusiasm and ambition when designing lessons. During her participation, Dakota worked with her mentor and group of other colleagues to design lessons together, which created a social context supportive of CT innovation in the classroom.

Dakota’s final lesson plan focused on energy transfer and started by engaging students with an online simulation where they could change different parameters to make waves. Then, Dakota and her mentor had students perform tests by “wiggling” coiled springs. Specifically, they tested the time it would take for waves to travel from one end to the other, and whether that time changed when more coils were added to the experiment. To answer these questions, students entered the data from their trials on Excel and decided how to sort those data. This exercise allowed students to find patterns, notice outliers, and make conclusions about waves and energy transfer. Dakota’s appropriation of CT during the STIG^{CT} best fits the Simulations for Visualization and Investigation profile. She particularly supported students in using the simulation as a platform to make tests on their predictions with Excel as an additional tool to analyze the results of those tests.

Enterprising Approach to CT

During the STIG^{CT}, Dakota worked with her mentor to learn about CT and design lessons for their shared classroom. She had a seemingly trusting relationship with her mentor, who was an experienced 4th grade teacher on her second year of STIG^{CT} participation. Dakota would often challenge her mentor to make their lessons more computational. For example, when her mentor was suggesting a seemingly typical science lesson activity, Dakota questioned: "So, is this computational? How do we make this computational?" Similarly, when her mentor seemed to continue down a path where CT in the activity was unclear, she directly asked: "What’s the computation there?"

This reflexivity about the computational aspect of lessons was also shown in her session reflections. In those, Dakota showed a curiosity about the boundaries of CT by asking questions about its definition, whether CT had to be "plugged in" and whether the lessons she was designing were "enough." While she was interested in integrating CT through unplugged activities, she also wanted to make sure that those activities counted as integration. Overall, her suggestions during lesson seed planning showed that Dakota had a solid understanding of CT and often aimed to bring other teachers around to integrating more computational activities.

Her lesson reflection shows Dakota was satisfied with the impact of her activities and explained that students were able to understand differences in energy transfer by engaging in the simulation and the coil trials. Yet, she identified ways to add opportunities for students to engage in CT such as adding more trials to enable conversations about data accuracy, collecting data on online simulation runs, and flipping the order of the activities so that the physical experience serve as a warm-up to the overall lesson.

Dakota's ambition on CT integration also appeared on her perspective of the role of CT in elementary schools. In focus groups, Dakota explained that, as a 4th grade teacher, some of the challenges of integrating CT at her grade level are due to kids having no familiarity with CT. She expressed that it would be ideal to start CT exposure in 1st grade at "a basic level" so that teachers can integrate more complex practices later in elementary school.

Overall, Dakota's case as a teacher who appropriated CT through Simulations as Visualization and Investigation tools demonstrates how personal enthusiasm and "buy-in" can encourage more ambitious integration of CT—even pushing experienced mentors who are more likely to maintain their traditional instructional approaches. However, her integration of CT *after* the STIG^{CT} illustrates how these intentions can be quelled by an unsupportive environment that discourages classroom innovation and experimentation.

CT Integration after the STIG^{CT}

After participating in the STIG^{CT}, Dakota started teaching in a new school, in a new district, and transitioned from 4th to 3rd grade. She was also tasked with all subjects, including science. In her new school, students were grouped in classrooms of mixed ability. Dakota's integration of CT was characterized by a school administration that aimed for classroom homogeneity and, in opposition, her determination to maintain some level of control over instruction.

School Uniformity and Barriers to Innovation

Dakota described her first year of teaching as having a "very small amount" of opportunities to integrate CT, which she directly related to the way the science curriculum worked in her new district. Her planning for CT integration at her new position seemed to be plagued with obstacles and school-level barriers. When describing how the science curriculum worked at her new school and district, Dakota expressed difficulty in planning CT-integrated lessons. She explained that the science curriculum was "kind of choppy" and consisted of county-provided lessons that corresponded to a bin of materials sent each quarter to teachers. Dakota seemed to be constrained by this curricular dynamic:

> *Only two or three times did they [the county] give us a lesson that kind of involved taking it to the next step, taking that Computational Thinking, and being able to integrate that technology within Science.*

These difficulties in integrating CT into lesson planning were augmented by the personnel available in the school. The group of teachers Dakota worked with at Strawberry Elementary was "a completely new team. Everyone was new to the school and new to the curriculum" which forced them to spend considerable time each week getting acquainted with the provided lessons and leaving little room for innovations like CT. Moreover, attempting to integrate CT in *one* classroom like Dakota's was discouraged, as the school's principal promoted uniformity. Dakota explained this policy as being able to "walk in all of our classrooms at the same time and see the same thing." This meant that integrating CT into a science lesson required *all* teachers to integrate CT for that lesson.

Interestingly, Dakota also mentioned that her students had participated in an Hour of Code event in their media class. Although students had enjoyed themselves and Dakota thought that coding instruction was an important learning goal, the difficulty of meeting the already existing curriculum demands stopped her from building on those initial programming experiences:

> *some days it was hard to even fit science in… It was hard to justify adding in this extra thing [programming], when we were barely meeting the current needs, but I think my class really would have loved that and loved to learn about that*

For these reasons, Dakota's planning for CT integration was limited, and the two lessons that she described as having CT included very few modifications. While Dakota would have liked to integrate more complex CT practices, she cited a lack of resources and comfort as obstacles. She wished she still had available the technological tools that the STIG^{CT} had provided, as having them at her disposal for lesson planning would make it more likely that she would use them.

This environment that promoted homogeneity across classrooms and had few opportunities for innovation greatly impacted how Dakota planned for CT integration. However, she was able to make small modifications to lessons, particularly at the time of implementation and when deciding on how to execute the details of county-provided lessons. Below, I describe how Dakota implemented her two CT-integrated lessons while aiming to regain or maintain some instructional control.

Maintaining (some) Instructional Control

While Dakota had little power in the design of science lessons, she focused on promoting CT practices when implementing lessons. Specifically, she aimed to provoke important discussions and guide students towards making data-based observations.

In her first lesson integrating CT, Dakota had students play a "prey and predator" game, much like the Oh Deer game that she had seen in her Science Methods course a year before as a resident. In this activity, students played the role of coyotes and rabbits. Coyotes were tasked with catching rabbits, who in turn tried to capture food (represented by footballs) while avoiding the coyotes. Students at each “round” recorded how many animals survived and how many managed to get food.

As explained by Dakota, the goal of the game was for students to understand that animals had a higher likelihood of surviving and getting food if they worked together. When “rabbits” scattered, they were less successful than when they strategized to create distractions and avoid the coyotes.

The first modification Dakota made to this lesson was to take the game outdoors because she had a “really big class”. Anticipating that all students needed to be engaged, she also made sure that every child had a task—half the students played the game while the other half recorded the results and made observations.

But, when the first round of the game showed that students were not incorporating the concept of collaboration among “rabbits,” Dakota stopped the lesson and made another instructional decision. She reminded students of their previous knowledge about animals, their behaviors, and adaptations. Since she saw that kids were playing the game rather randomly, Dakota decided to re-iterate the goal of the lesson and how it connected to their learning about animal collaboration and adaptation. This, she hoped, would re-focus students on the relationship between the science content they were exploring and the activity.

After the game was over, students moved on to the part of the lesson which Dakota identified as engaging students in CT. Specifically, they “brought that data back, and kind of analyzed it, and compared the different environments and scenarios.” In an effort to promote data-based decisions, Dakota encouraged students to look at the data from the game and compare results between rounds where cooperation was used and not used.

In the evaluation stage of the lesson, Dakota made another small modification to engage students in CT and data-based decision making. Instead of asking students a question about animal behaviors impacting survival as the original lesson plan expected, she built on the data activity and asked students to discuss why the numbers between each round (before and after “rabbits” started collaborating) had changed. These small changes represent Dakota's intention to integrate *some* CT through the implementation of a lesson plan that she had little power to modify.

Dakota's determination to maintain some instructional control was also evident in the second CT-integrated lesson she implemented. This lesson started with a video of rollercoasters to engage students and followed with a multi-day plan. Students used different materials to create ramps and tested how far ping-pong balls traveled when dropped from the top of the ramp. Students conducted three trials per ramp and entered their data (height of ramp and ball distance traveled) into a class-wide Excel sheet. Then, they analyzed their results through graphs and wrote their findings as an exit ticket.

During the initial portion of the lesson, she led a discussion around the speed of the rollercoasters and whether the slope or the height of the ride had an influence on how far or fast they went. She used this discussion to guide students in making hypotheses and set up the rest of the lesson: "[I] never give the correct answer. It was all [student] predictions and they gave their reasonings and we had discussions and then we said we were going to test these ideas." Once again, after students had entered the height of their ramps and distance traveled into an Excel sheet, Dakota asked students to make explain what they had learned "using a data point." This type of assessment was Dakota's way of ensuring that students had engaged with the content and the CT practices.

Dakota saw her two implemented lessons as positive integrations of CT that were productive for her students, although some seemed to benefit from CT more than others. When looking back at the implementation of her two lessons, Dakota saw CT as a positive improvement over strict adherence to the curriculum:

> *I thought it [CT] made the lessons resonate with them [students] a little more, than it would have if we just did an activity and moved on. It caused them to think on a higher level and think about the impact of what we were doing, not just doing an activity and moving on.*

When discussing what students did successfully, Dakota highlighted their ability to notice patterns in the data from the game, such as differentiating rabbit survival numbers between rounds where they worked individually and where they worked together. She also mentioned that, in the second lesson, students had successfully constructed their ramps and learned from the graphing classroom data.

However, she also recognized that the positive impact was not evenly distributed among her students. For example, when recalling the lesson with a simulation, she explained that students who were willing or able to “give the technology a try independently” were able to engage with the simulation more productively than those who needed more support. Nevertheless, this disparity was not necessarily tied to CT lessons, these students typically had more difficulty “click[ing] the lesson and the meaning together.”

Dakota’s suggestions for improvement on the lessons reflected her goal of promoting data-based conversations as a way to engage in CT. She specifically suggested adding more discussion time to her future CT-integrated lessons, as those conversations could help *all* students grasp the connections between the simulations and the science content of the lesson. She also suggested adding more simulations to each of the designed lessons, and even talked about the possibility of students making animations in Scratch about their learning.

These additions would represent a return towards the inclusion of computational devices that Dakota showed in the STIG^{CT}. However, it is unclear whether she would be able to implement them in her current school, as it would also require for other teachers to adopt the modifications as well.

Case Conclusions

Overall, Dakota’s appropriation of CT changed from her participation in the STIG^{CT} to her first year of full-time teaching. While her participation in the STIG^{CT} was marked by enthusiasm about integration and an enterprising approach that pushed her own mentor to create lessons with a computational aspect, her new position prevented her from replicating that approach. In the year following the STIG^{CT}, Dakota was only able to make small modifications to county-provided lessons and was not able to appropriate CT through simulations as she had in the past.

These changes in appropriation, however, did not appear related to changes in her conceptualization of CT or in personal characteristics. Instead, they seemed to be directly related to her new school’s emphasis on following the established curriculum and her lack of instructional time dedicated to science. Without technology available, a group of teachers who were as unfamiliar with the curriculum as her, and an administration that encouraged uniformity across classrooms, Dakota had no power to plan for CT integration.

Instead, she aimed to make small edits when implementing county-provided lessons to ensure that students engaged in some CT practices. She focused on creating opportunities for students to use Excel to record and analyze data while explicitly promoting discussions based on those data.

Dakota's case adds more evidence to the role of the social context in the appropriation of CT and the limitations of conceptual understanding and personal characteristics as factors impacting CT integration. Specifically, she exemplifies a teacher who graduated her teacher education program and the STIG^{CT} with a good conceptual understanding of CT, a high level of enthusiasm about integration, and an enterprising attitude that could lead her to design lessons that engaged students in multiple CT practices. Yet, in a social context that explicitly stifled her opportunities for lesson planning, her conceptual understanding and personal characteristics only had a limited impact on how much CT she was able to integrate. Dakota's case is perhaps the clearest of this set in suggesting a more *hierarchical* relationship between the three factors that impact CT appropriation. In other words, her case suggests that conceptual understanding, personal characteristics, and social context may not impact appropriation equally. Instead, a social context that *allows* for appropriation may be a pre-requisite for conceptual understanding and personal characteristics to come into play.

Ella: Broadening CT while Meeting Student Needs

Ella participated in the STIG^{CT} as a 5th grade teacher and returning resident (meaning she had participated in the previous version of the STIG^{CT} as a resident). She was the only teacher to integrate CT in a way that supported scientific inquiry and most closely resembled the type of integration researchers advocated for. Ella was knowledgeable about CT, often discussed the practices with peers and researchers and believed CT was important to students' development and that they were prepared to engage in complex practices like programming. She also worked within a social context that supported her integration of CT: she had a leadership role in the STEM education of her school.

After the STIG^{CT}, however, Ella changed schools and faced a new context that made CT integration more difficult. Her new students needed additional support and she did not see them as ready to engage in the most complex CT practices she had implemented in the past. She also explained that her view on CT had shifted since her participation in the STIG^{CT}. Ella now saw CT as more generalized, present in all subjects beyond science and functioning as a building block to learning—not just a skill to be used in science. As a result, her integration of CT was less technology-based and more focused on building the basic skills of pattern recognition. Ella showed the most drastic change in appropriation, going from CT to Support Scientific Inquiry in the STIG^{CT} to an integration that better resembled Appropriating CT Labels.

Ella in the STIG^{CT}

Ella's participation in the STIG^{CT} is detailed in the profile *Integrated CT to Support Scientific Inquiry* (Ch. 4), as she was the only teacher to appropriate CT in that way. To avoid being repetitive, I only summarize her participation in the STIG^{CT} in this section. Ella participated in the PD as a returning resident during her first year of full-time teaching. She was the only participant from her school, where she oversaw the Makers afterschool club. In this club, Ella led students in working with different technologies, like Makey-Makeys and Scratch, to create artifacts and applications based on student interests.

Ella demonstrated a good conceptual understanding of CT and was consistently curious about its boundaries and definitions. She often engaged in discussions with researchers during lesson co-design sessions and expressed some of her questions on written reflections. She was eager to learn more about CT, compared her experience to the time when she participated in the first STIG^{CT} year as a resident, and looked forward to continuing integrating CT in the future.

Her personal characteristics included a critical eye towards her county's science curriculum but she saw CT as a way to improve it. She believed that students were naturally proficient with technology and viewed CT as a necessary tool to prepare her kids for a computational world. She also described her administration as supportive of innovative science education and was in charge of a Makers after school program where students learned to use different technologies to create artifacts and products.

Her final STIG^{CT} lesson focused on water pollution and engaged students in thinking about a computational device—the micro:bit—as a data collection tool. Students created a program to use the device's photosensors to test how much light went through water with different levels of pollution. They also downloaded and analyzed the micro:bit data and discussed differences between their experiment and testing water in the field. This lesson demonstrated a conceptual level of appropriation and fit the profile of Supporting Scientific Inquiry through CT. However, after being the only teacher to reach this level of appropriation in the STIG^{CT}, Ella was not able to replicate that experience in a new teaching job. In her new school, she faced new challenges that prevented her from integrating CT at the level she would have liked to and instead opted for an approach that better fit the needs of her students.

CT Integration after the STIG^{CT}

After her participation in the STIG^{CT}, Ella shifted to a more rural school where she was assigned to teach all subjects in 5th grade. Her planning and implementation of CT-integration lessons were heavily impacted by the academic needs of her new students. She also seemed to develop a more generalized conceptualization of CT—dissociated from computing and more closely related to dispositions and logical thinking.

Adapting CT to Student Needs

Ella's classroom was composed of 27 students of different academic levels, half of them with IEPs or 504s.[3] The additional support her new students needed seemed to be taxing on Ella's ability to plan and implement CT-integrated lessons. While she would have liked to integrate complex CT practices like programming through tools like micro:bits and Scratch, she said her new students were simply not ready yet for that kind of instruction:

> *I'm super, like, math- and science-driven. I want to go off the deep end in science and just get super deep, but this year definitely was a little bit harder for me.*

Instead, Ella aimed to integrate CT in ways that would support her student's general development—especially those with special needs. As multiple kids needed frequent breaks and dealt with anxiety issues, she sought to give them options where they could develop CT skills through games in a low-stress environment.

Particularly, Ella provided students with a series of logic and puzzle games that they could use to take "brain breaks." While these games were not part of a specific lesson, Ella saw them as opportunities for students to start developing the necessary skills to engage in CT in the future—a form of CT pre-requisite. Specifically, she saw the games as promoting systems thinking, troubleshooting, and learning about conditionals.

These games included Rush Hour, Chocolate Fix, and a laser logic puzzle. In Rush Hour, the player has to arrange different plastic cars in a predetermined order, then figure out how to move them around so that the main car can exit through a gap on one side of the board. In Chocolate Fix, the player has to arrange "chocolates" which have certain colors and shapes into a 9-slot tray. Each challenge has three sets of chocolate arrangements that must be met at the same time. In her words, these games "introduced them

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[3] IEPs, or Individualized Educational Plans, and 504 Plans are programs developed to ensure children with an identified disability receive specialized instruction or appropriate accommodations.

to that way of thinking [CT] on a level that did not maybe create some of the worry or anxiety" associated with typical instruction.

Ella's implementation process followed her idea of developing CT pre-requisite skills in a way that was appropriate for the academic level of her students. When children were playing the games she had provided as breaks, Ella would use a questioning method to help students develop the habit of thinking ahead:

> *So a little bit of the way how I would scaffold [the games:] Some of the questioning with the kid was as if [they were] one of my higher level students. I would just ask, What's your goal? Like, where do you want to go and why? So, they have to do that backwards mapping and making sure that they still have an endgame in mind.*

However, the demands of her classroom prevented her from scaffolding this game-playing consistently. Often, when students played these games as a break, Ella was busy supporting other students through their curricular learning. The best opportunity for this type of individualized support would take place at the *end* of the day, when students would have some time to play the games before they left school.

When planning for her second instance of CT integration, Ella again included activities designed to develop the "pre-requisites" for engaging in CT. Ella integrated CT in a multi-day project where students explored the different spheres of the Earth—a common topic for her county's 5th grade science curriculum. In this extended lesson, students searched for information of each sphere on the internet, drew pictures and infographics of the information they found, and created a final poster that described how sphere interacted with each other. In Ella's view, students engaged in the CT system thinking practices because they had to consider how each sphere contributed to Earth as a system. She also described the creation of the final poster as engaging students in modeling since the poster was meant to represent (or model) Earth.

However, Ella explained that her goal with the unit was to support students in developing the skill of recognizing patterns. Considering her students' lack of familiarity with programming, Ella on creating a paper-based project instead of incorporating digital tools that could add another learning barrier:

> *I couldn't necessarily just give them Scratch and like teach them Scratch and then have them create that model [of Earth].*

When reflecting about her integration of CT, Ella saw obstacles beyond students' academic abilities. For example, she also complained about science instructional time constraints. She particularly lamented not having enough time to create "personalized lessons" where kids who *were* ready to engage in more complex CT practices would have the opportunity to do so. For example, she applied and received a grant to buy micro:bits for her school, but could not find an appropriate time to use them with her class. Even when she planned to have some optional activities as lesson extensions, she would "end up teaching more to my lows as a whole because of timing."

Overall, student needs seemed to be an all-encompassing factor that conditioned Ella's planning for CT integration. After recognizing that a portion of her students needed to develop basic pattern recognition and self-regulation skills, she sought to provide activities that would develop those skills and prepare them for CT engagement in the future. And, while she had technology available and *wanted* to teach more complex lessons that involved computational devices and programming, she sacrificed those instances of CT for options that better fit the academic needs of her students and the amount of science instructional time she had available.

Broadening the Conceptualization of CT

Beyond the challenges of meeting the needs of her new students, Ella also demonstrated that her integration of CT was affected by a change in how she conceptualized CT. She explained that she underwent an important reflection process regarding CT following her participation in the STIG^{CT}. She specifically described coming to the conclusion that CT "parallels the ways we want children to learn" and recalls noticing instances of CT in subjects beyond science:

> *one the biggest 'ah-ha's' that I had from doing the CT workshop [STIG^{CT}] with you was understanding how a lot of these systematic thinking—that the competencies really parallel to the ways that we want children to learn reading and math. Like sequencing—that is understanding patterns, understanding sequencing. [...] Well, guess what? They actually do that every single day in reading. They have to sequence stories and they also have to find patterns in the story to understand the main idea, or to understand author's purpose, or whatever the objective is.*

This development of a more generalized view of CT impacted how Ella interacted with students to promote engagement in CT. For example, with the goal of helping students develop patter recognition skills—a part of CT in her view—she would repeatedly ask students who were looking for Earth spheres information to think of times when they may have encountered similar information. She also reminded students that they had successfully engaged in some pattern recognition when they played the games, encouraging them to think back to those experiences and try to apply similar strategies when analyzing Earth's spheres information.

This generalized view of CT also impacted how Ella assessed the success of her lessons. Instead of evaluating whether students had understood computing concepts or demonstrated improved science learning, her reflections focused on the goals of developing more generalized thinking skills. Specifically, she saw the integration of the games as productive, and noticed more "genuine stamina and engagement" in students playing the game than when going through other typical science or math topics. Ella saw growth in her students, particularly an improvement in their ability to recognize patterns and "more strength in the higher order thinking that they struggled to do [at the beginning of the year]." At the same time, she highlighted that the games had successfully served a "calming" function for students who had high anxiety, issues with emotional regulation, or ADHD.

However, Ella's new and broader perspective on CT was not *devoid* of connections with computing. Instead, she seemed intent to introduce students to these concepts in a way that was not directly associated with computational devices but required a similar thought process. For example, Ella explained that the

Rush Hour game, where students had to solve a puzzle to get their car out of a traffic jam, introduced them to the concept of conditionals—a key computing concept:

> *…like your personal car is the red car and you have to get the red car out of traffic. So, a lot of that like—I think the system's thinking and so like the progression, like understanding 'if you do this, this is going to happen' with some of those conditionals and also you visualize how you're going to create that solution. And it has a lot of that troubleshooting and it has a lot of those competencies. So, I chose a lot of games like that.*

Ella also believed that students should see connections between the different CT activities students engaged in and used vocabulary building to make those connections. When implementing her lessons, she purposefully used words like *pattern*, *inference*, *abstraction*, and *troubleshooting* with students so that they would get used to and incorporate those into their repertoire. Her goal was to be able to use those words in the future during other activities so that students would remember how they had engaged in these CT practices as a way to solve new problems.

In summary, Ella's perspective of CT seemed to retain some connection to computing concepts but had also expanded to include instances where students used more general thinking strategies applicable to all subjects. This perspective resembles Bridget's experience and, again, is in line with some arguments of CT as a problem-solving strategy applicable to all kinds of problems. However, this generalized view does step away from the perspective promoted in the STIG^{CT}—which aimed to define CT more narrowly as a set of practices, connected to computing, that could serve scientific learning.

Nevertheless, the application of this more generalized view of CT may depend on the academic level of Ella's students. At the time of the interviews, Ella was already planning on changing schools and described the students she would be working with as academically higher than those she had worked with in the year after the STIG^{CT}. This new context would give her the opportunity to integrate computational simulations and have students make "stronger generalizations from using these tools" than the students she had just worked with. It is possible that, in working with students who Ella considers able to engage with more complex CT practices, she would design and implement CT-integrated lessons more directly connected to computational devices and computing concepts in the service of science learning.

Case Conclusions

The case of Ella shows how a teacher who was able to appropriate CT at the highest level during the STIG^{CT} was unable to replicate that integration of CT in a different teaching context. Ella’s changes in appropriation were quite extreme: she went from programming a computational device to collect data and answer a scientific question to providing logic puzzles and encouraging pattern-finding while making posters. Neither of these latter instances of integration were directly linked to computing. To be clear, I do not intend to say that the activities Ella provided for her students were not helpful to their development or learning. My evaluation is based on whether they fit the goal of CT integration that researchers stipulated in the STIG^{CT}: introducing students to computing in a way that supports scientific learning.

This swing in appropriation seemed to respond to two major forces. The first was contextual: her new students needed additional support and, in Ella’s view, simply were not ready to engage in complex CT practices like programming. Importantly, her access to technology had not changed, and she did not particularly identify a lack of administrative support for CT integration. Instead, the main change in her context was the academic level of her students and how that impacted her ability to engage them in certain CT practices like programming. The additional support her new students required also impacted her ability to personalize instruction and plan for different ways of engaging with CT.

The second force driving her integration of CT was related to her understanding of CT, which seemed to have become more generalized after her STIG^{CT} participation. With a new perspective of CT as present even in Reading education, Ella saw activities where students looked for patterns as sufficient to count as CT. This impacted the types of thinking she encouraged in students, how she interacted with them to promote those types of thinking, and which activities she saw as engaging students in CT.

It is likely that these two forces reinforced each other. For example, a broader perspective of CT that is not necessarily attached to explicit computing activities allowed Ella to describe the games, which promoted skills like logical reasoning and pattern recognition, as being within the confines of CT integration. At the same time, it is possible that Ella's experience working with students with higher academic needs helped her see that CT engagement can go beyond programming. Namely, that students can engage in the same types of thinking *without* the barriers that computational devices sometimes entail.

Integration of CT after the STIG^{CT} Across Cases

The case studies described above demonstrate how teachers who appropriated CT in different ways in the STIG^{CT} integrated CT in the year following their participation. Specifically, they show how aspects of their social context, their personal characteristics, and their conceptual understanding of CT impacted how they planned, implemented, and reflected on CT-integrated lessons. The cases, seen together, demonstrated patterns in how teachers navigated their educational contexts and applied their learning from the STIG^{CT} after the PD concluded. While each teacher represents a unique case of CT integration, an analysis across cases illuminates the relationship between appropriation during the STIG^{CT} and integration of CT following the PD. Specifically, different patterns emerged on the roles of CT conceptualization, personal beliefs, and teachers' school context in determining CT integration after the STIG^{CT}.

STIG^{CT} Appropriation and CT Integration after PD

The case studies serve as evidence to respond to the second research question of this dissertation: *How do different types of CT appropriation correspond to teachers' reflections of their CT integration within their classrooms?* Looking across cases, teachers' appropriation of CT during the STIG^{CT} seemed to be linked to how they reflected on their integration of CT *after* the PD. For example, Anna, who had appropriated CT labels in the STIG^{CT}, continued to do so in the subsequent year. She saw her curriculum as being already integrated with CT practices and continued to use language of CT framework to describe typical science lessons. Similarly, Cassie based her CT integration on the examples she saw on the STIG^{CT}, and she replicated the lesson that demonstrated a Surface level of appropriation during the PD

(Simulations for Visualization and Investigation). Dakota, within her limited sphere of control, again tried to engage students with a simulation as she had done in the STIG^{CT}, although she could only engage them in an “unplugged” version in the following year. As she had done in the lesson designed for the STIG^{CT}, she still encouraged students to make conclusions based on their experience with that simulation.

Bridget, who added new ways of integrating CT after the STIG^{CT}, still demonstrated some relationship to how she had appropriated CT during the PD. In the year after the STIG^{CT}, she again integrated a programming activity as an extension but tightened the connection between that programming activity and the science concept. Additionally, since her conceptualization of CT had expanded, she also integrated CT in new ways that were not clearly related to her STIG^{CT} experience.

Perhaps the exception to this relationship between appropriation during the STIG^{CT} and after the PD is represented by Ella. After being the only teacher to appropriate CT at the highest level in the STIG^{CT}, she faced challenges meeting the needs of her new students and developed a more generalized view of CT. These two factors seemed to lead to integrations of CT that were largely disconnected from her appropriation in the STIG^{CT}. The role of conceptualization of CT and teachers’ context on CT integration is further discussed below.

Building on STIG^{CT} Appropriation

These cases suggest that the level and style of appropriation demonstrated during PD can serve as a baseline for integration of CT in subsequent years. In cases where teachers had opportunities for reflection and careful planning, teachers were able to build on their appropriation—albeit modestly. For example, Bridget was able to improve on her appropriation of CT through programming by making the connection between the coding activity and the scientific content more explicit. Cassie, likewise, took an incremental approach to her lessons and added scaffolds to organize how students interact with computational simulations, although she did not anticipate including conversations about those simulations as computational artifacts. She did, however, show potential for expanding her integration of

CT towards programming activities using the Code-a-Pillar, but the difficulty in acquiring the devices prevented her from implementing that lesson.

Maintaining or Regressing from STIG^{CT} Appropriation

On the other hand, in cases where teachers *did not* have opportunities to build on their CT appropriation from the STIG^{CT}, the integration of CT suffered. For different reasons, the lessons that Anna, Dakota, and Ella integrated showed no progress (and Ella's case clear regress) from their appropriation of CT during the PD. Anna, who remained constrained by obstacles to integration, continued to use language from the CT framework to describe her county's science curriculum. And, although her students showed interest in programming, she could not overcome the barriers that prevented her from implementing those practices in the classroom. Therefore, she did not progress from her appropriation of CT labels at the STIG^{CT}.

Dakota went from engaging students with a computational simulation in order to explore the topic of waves to limiting her CT integration to instances of discussion of data-based decisions and Excel data collection. While this change in integration is not a clear regression in terms of appropriation level, Dakota's testimony shows that she would have liked to *build* on her use of computational simulations, not take those away. Her decision to have data-based discussions with students was an attempt to integrate some CT practices into a lesson that she had little control over. But, in her interviews, Dakota shared that the lessons could be *improved* by adding computational simulations or even programming activities in the future. Therefore, her level of appropriation did not seem to progress and, in fact, the lessons she implemented seemed to have *lost* some of the connection to computing by removing the engagement with computational simulations.

Ella's case, on the other hand, represents a clear regress in appropriation of CT. Granted, the lesson that Ella designed during the STIG^{CT} was exemplary, and maintaining that level of appropriation was a high bar to establish. However, the stark contrast of her appropriation during the STIG^{CT} and after the PD show the important influences that teachers' context and conceptualization of CT play in how they integrate CT. In working with students with extensive academic needs, Ella was unable to use CT practices like programming and instead focused on building “pre-requisites” for CT engagement. Her description of typical scientific practices like observing patterns as fitting under CT most closely resembled an appropriation of labels, the opposite end of the appropriation spectrum.

Taken together, the cases suggest that growth towards more advanced levels of appropriation is difficult or unlikely in the first year after the PD without purposeful support and scaffolds. While some teachers showed slight progress in how they implemented their CT lessons, none of the five teachers clearly reached a higher level of appropriation in the year after the STIG^{CT}. Unfortunately, some seemed to regress towards lower levels, often influenced by changes in their view of CT and contexts that did not support its integration.

The role of CT Conceptualizations

In the five case studies, the way that teachers conceptualized and defined CT played a role in how they planned for CT engagement, implemented their CT lessons, and reflected on how students had engaged in CT. Specifically, these views impacted what activities they saw as engaging students in CT, and therefore determined how they reflected on “successful” implementations of CT integration.

Generalization of CT. Teachers’ conceptualizations of CT seemed to move away from a computational perspective after the STIG^{CT}. Most markedly in the cases of Bridget and Ella, their definitions of CT—and therefore its applications—were dissociated from engaging with computing devices or leveraging computing concepts for science learning. Instead, their perspective of CT focused on capturing they types of thinking that students engaged in when doing programming activities and replicating them through non-computing activities. As explained in Bridget’s case, this line of argument, where CT is positioned as a generalizable problem-solving strategy to be applied in any subject is in line with multiple advocates of CT in K-12 education (National Research Council, 2011; Wing, 2006).

However, this view is distanced from the definition of CT provided in the STIG^{CT}, where CT is positioned as a way of leveraging computing concepts in the service of science learning (Ketelhut et al., 2019). This narrower perspective of CT argues that CT integration into science learning at the elementary level serves two functions. On one hand, it introduces students to computing concepts so that they can, at a later age, be prepared to successfully engage with computational devices and computing activities. These experiences will allow more students of all backgrounds to access and succeed in computing education. On the other, this perspective argues that much of professional science is carried out with the support of computing, and that students should begin to leverage computing for science learning if they are to be prepared for professional science. This argument does not, however, position CT as a set of *generalized* practices. Instead, since the goals of integration are related to access and success in computing and science, this position argues that the practices should be interpreted *through a computational perspective.*

Yet, this argument, which was held with varying degrees of conviction by the researchers of the STIG^{CT}, did not seem to represent how teachers thought of CT after the PD. In contrast, teachers developed a more generalized view of CT and intended to replicate the same types of thinking that made students successful in computing activities to apply them in non-computational activities. It is possible that the development of these perspectives is related to teachers' conflation of CT with "good learning" or productive learning practices. As Ella suggested, some of the practices that the CT framework enumerates (like *Breaking down problems into smaller parts*) are simply productive practices that can help in *any* type of problem. This perspective can make it seem like other practices that are helpful to solve a variety of problems can *also* fall within the realm of CT.

This conflation was most evident in how teachers *described* CT engagement in their lessons—often naming generalized skills that did not come from the CT framework. For example, Bridget talked about pattern recognition and troubleshooting, skills that she valued and could be associated with some CT practices but were not extracted from the CT framework. Similarly, Ella mentioned the concepts of sequencing and conditionals, which are clearly related to computing but not mentioned in the framework.

In both cases, teachers talked about these skills as if they were CT practices—demonstrating an expansion of CT to include other skills or concepts related to computing than those shared in the STIG^{CT}.

To be clear, this study does not suggest that this expansive view of CT is detrimental to CT integration. However, it is important that PD designers and researchers understand how these types of generalized views of CT impact how teachers design and implement CT-integrated lessons.

Impact on Planning and Implementation. Teachers' conceptualization of CT impacted how they designed their CT-integrated lessons. Anna, who saw CT as a broad category that included typical science practices, did not need to plan for CT at all—she saw it as already embedded in the curriculum. In Bridget's case, her definition of CT as a set of dispositions led her to plan a lesson that required students to engage in a productive type of frustration. Similarly, Ella's newly developed generalized view of CT allowed her to provide games that promoted pattern recognition as instances of CT integration.

The role that that conceptual understanding played in appropriation of CT seems to contribute to the understanding of appropriation of pedagogical tools that Grossman et al. (1991) proposed. While the cases show that conceptualizations of the pedagogical tool (CT) were somewhat determinant of teachers' appropriation styles after the STIG^{CT}, the experiences of these teachers also suggest that their conceptual understanding impacted planning and implementation differently depending on the context teachers worked in.

In contexts where teachers had the flexibility to plan their own lessons, such as Bridget, Cassie (with some time constraints) and Ella, conceptual understanding of CT seemed to play an important role in lesson planning and implementation. The teachers' ideas of what CT entails were materialized in the activities that they included in their lessons and how they facilitated them during implementation. It also impacted how they reflected on those same lessons and whether they saw successful CT engagement in them.

On the other hand, in the cases where teachers had little autonomy over lesson planning, conceptual understanding seemed to play mostly a role in implementation. Specifically, it impacted how teachers interacted with students and the types of discussions they facilitated for them as a way to engage them in CT. For example, in Anna's case, while she had no power (nor intention) to change the lesson plans to integrate CT, her views of CT impacted how she supported students. For instance, her view of CT as including the processes of "designing and evaluating" likely influenced her decision to ask students to take steps that would ensure they engaged in those process. For example, she asked students to make plans for their cars ahead of time, to make sure to use the wheels they had available, and to test their models before completing them.

Similarly, Dakota, who had little say in the design of science lesson plans, was able to make decisions on how she interacted with students as a way to support their engagement with CT. Specifically, she focused on promoting data-based decisions, asking students to compare rounds of the predator-prey game by looking at the numbers of each round.

These cases show that conceptualizations of CT played an important role in how teachers implemented CT-integrated lessons and, in cases where teachers had some control over lesson design, in how they planned for CT integration. Yet, the level of influence teachers had over lesson design was often a function of the context they worked in. Context, it seems, had an overarching influence on teachers' CT integration after the STIG^{CT}.

Impact on Reflection. While each teacher had a different set of students and worked in different schools, there was a remarkable degree of similarity when they reflected on the impact of CT integration. How teachers conceptualized CT and integrated it into their lessons was evident in the insights they gained from them. All case study teachers saw CT as a positive addition to their instruction—they saw benefits of integrating CT. Three teachers (Bridget, Dakota, and Ella) saw an improvement in students' pattern recognition skills, which they directly associated with CT. Cassie highlighted how CT had made her science lessons engaging, and Anna described her lessons as "a lot of fun."

They all also saw potential improvements in their lessons and wanted to make changes in the next year to their integration of CT. Anna thought she could enhance CT engagement by making the tasks in her lesson more complex, Bridget wanted to use more robots the next academic year, Cassie aimed to provide more structure to her simulation activity, Dakota would add discussion time to connect the science content with the simulation students played in, and Ella looked forward to integrating more complex CT practices with a group of students that required less specialized support.

Yet, this optimism was also countered by a set of barriers that teachers identified preventing them from implementing CT as they would like to. Anna thought Scratch could be productive for students and that they would like to use it, but she simply did not feel comfortable enough to integrate it in her classroom. Cassie just did not have time to plan for integrating CT into other lessons and did not see more opportunities for integration without having material resources available at her school. Ella, on the other hand, lamented that her students were not ready for engaging in the complex CT practices she liked to implement, and wanted to make sure she met her students at their level instead of burdening them. Bridget, once again, was the counterexample—she thought that the following year, with an even more experienced teaching team and available resources, would allow for further integration of CT and robots.

The role of Context

After co-designing lessons with the support of peers and researchers in the STIG^{CT}, teachers had the opportunity to continue their CT integration in the year after participation. In three of the five cases (Anna, Dakota, and Ella) teachers changed schools between the STIG^{CT} and the following year. These changes, along with the faded support that the STIG^{CT} used to provide, seemed to greatly impact teachers' ability to plan and implement CT-integrated lessons. Specifically, teachers faced a number of obstacles that made planning for CT integration harder. In limited cases, they also were able to leverage resources from their context to *improve* their CT integration, but these were more exceptions than the norm.

Perhaps the most evident influence of context on the planning process is illustrated by the cases of Anna and Dakota. As first-year teachers in schools that heavily monitored the science curriculum, both teachers struggled to plan for CT integration. In Anna's case, her control over science lessons was yielded to the county, who mandated the curriculum and even sent her the necessary materials to carry out the lesson plans. Dakota, on the other hand, faced an administration that promoted homogeneity across classrooms, impeding her from experimenting in her own lessons. While she still tried to integrate CT by asking data-related questions, her ability to integrate other practices was limited.

But, in the cases where teachers had *some* control over their lesson plans, other obstacles made CT integration difficult. Cassie, as an experienced teacher, seemed to have the ability to make small modifications to her lessons, but complained that the labor of planning and designing for those modifications had to be done on her own time—a resource she was not willing or able to spend. And, even when she managed to design a new lesson for CT integration, the barrier of acquiring the necessary materials prevented her from ever implementing it.

In Ella's case, where she seemed to have the freedom to dictate how her science lessons were designed and implemented, the context of her school and the academic needs of her students constrained the types of practices she could integrate. Even when she saw opportunities for *some* students to engage in more complex CT activities, she had to sacrifice those opportunities to spend more time supporting students with greater academic needs. These contextual factors led her to integrate CT through games and other typical science activities that were unrelated to computing.

Bridget's case, which serves as a counterexample here, confirms that context is highly influential in how teachers design and implement CT-integrated science lessons. Bridget did not face the same barriers that other teachers in this study did. On the other hand, her school had technology available, was designated a STEM school, promoted experimentation in the classroom, and even allowed teachers to co-design science lessons while helping each other out in the classroom. As a result, Bridget expanded on her appropriation of CT from the STIG^{CT} and again integrated programming activities—albeit with a closer connection to science. She also expanded her integration to other subjects beyond science, although she integrated a modified version of CT that was more generalized than the perspective shared with her in the PD.

Taken together, the cases suggest that, while some teachers were able to push back against limiting factors, context plays a key role in providing teachers with the ability to plan and implement CT-integrated science lessons. Ironically, the context in which teachers work is outside of the reach of many PD programs, which focus mostly on teacher knowledge and skills. Below, I explore the implications of these findings for teacher professional development.

Implications for Teacher Professional Development

The finding that teachers mostly maintained their appropriation style after participation suggests that PD designers and researchers should aim to graduate their educators with the most sophisticated level of appropriation possible, and not expect their integration of CT to evolve quickly on its own. At the same time, each of the factors that impacted teachers' maintenance or regression in appropriation levels could be influenced during PD (Figure 9).

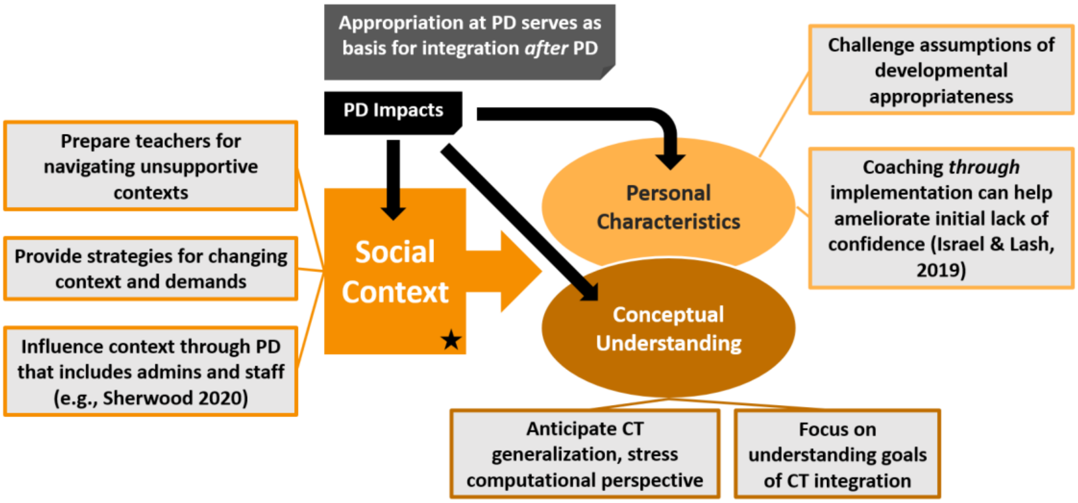


Figure 9. How PD can impact each factor that influences CT appropriation.

For example, this study shows that the concepts teachers learn about in the PD can morph and evolve after the program ends. In the case of CT, conceptualizations seemed to become more generalized and move *away* from a computational perspective.

Expecting CT Generalization

These findings indicate that PD designers who intend to support teachers in integrating CT should take the possible post-PD generalization of CT into account. If they want to prevent it, then they could be more specific about promoting a narrower view of CT and differentiating CT from typical science instruction or other productive thinking skills. However, not all researchers would agree with this narrower view of CT as a way to leverage computing concepts for science learning. Others who advocate for CT as a broad problem-solving skill could instead *leverage* the fact that teachers seem to generalize their understanding of CT as they integrate it into the classroom. These researchers could provide teachers with tools and examples to expand their integration of CT towards other subjects. The case of Bridget provides an interesting model: it seems like her experience *observing* students engage in programming convinced her that CT could promote a productive type of frustration. Researchers could aim to provide teachers with opportunities to participate in similar experiences, observing how students engage in computing activities and trying to replicate that type of thinking in other lessons.

Influencing Context

The STIG^{CT} aimed to support teachers in developing the skills to integrate CT into their elementary science instruction. However, the case studies presented above suggest that knowledge and beliefs, which the STIG^{CT} targeted, only play a partial role in determining how teachers design and implement CT-integrated science lessons. Context, particularly how much schools controlled the design of lessons, how much technology they had available, and how much instructional time they provided for science, seemed to be another major force.

Therefore, PD designers could take multiple approaches to, in addition to attending to teachers' knowledge and beliefs, influence how much impact context has over CT integration. Specifically, PD designers could tailor their instruction to alter the relationship between teachers' context and their ability to plan and implement CT-integrated lessons.

For example, PD designers could frame lesson planning activities around navigating existing curricula, identifying and using existing school resources, and assessing levels of support at each school. This would provide teachers with tools to continue their integration after PD, as it would provide practice in navigating the same constraints that would typically influence lesson planning “in the wild.”

Teacher educators should also focus on providing teachers with other tools to integrate CT once the available support during PD fades. These cases show that, for both novice and experienced teachers, designing and implementing CT lessons was a challenging task that only got more difficult after researchers and peers were no longer able to contribute their expertise. Other studies also affirm that continuous support, such as coaching, may be an effective tool to sustain integration (Israel et al, 2015). A place to start would be to encourage teachers who work at the same school, such as Cassie and her colleagues who participated in the STIG^{CT}, to advocate or look for opportunities for co-designing once the PD is finished. However, this may be beyond the reach of individual teachers and may be more appropriate as a goal for schools and counties.

Additionally, to influence how context impacts implementation, PD designers could provide opportunities for teachers to practice their lessons—particularly how they frame CT activities for their students and how their students react when engaging in CT practices. These activities could provide opportunities for teachers to identify contextual factors that impact how they facilitate their lessons while giving them a chance to discuss them with researchers and peers in the PD. These “practices” could both serve as formative assessments of teachers’ conceptualizations of CT and an opportunity to identify challenges that were unforeseen during lesson planning.

Chapter 6: Discussion

While chapters 4 and 5 contained their own discussion sections, I use this chapter to highlight findings from each analysis and further explore the connections between two parts of the dissertation. I also summarize the implications for teacher education detailed in the preceding chapters. Specifically, I attend to two major themes of the study: (a) the looming influence of context on CT appropriation and integration and (b) the role of CT understanding in these processes.

Teachers who participated in the STIG^{CT} appropriated CT in different ways. Almost all of them reached a Labels level or Surface level of appropriation, but those who reached the latter did so in different manners. Specifically, teachers appropriated CT by meeting one of the two goals required to reach the Conceptual level of appropriation. Some met the goal of introducing students to computing concepts by integrating programming activities as lesson extensions. Others met the goal of supporting scientific learning with CT practices by engaging students with computational simulations to visualize or investigate a scientific phenomenon. And yet a third group met both goals, but separately. Only one teacher, Ella, reached the conceptual level of appropriation by meeting both goals simultaneously.

The findings from the first analysis show that teachers' appropriation styles were heavily influenced by their social context such as the level of support for integration they had available at their schools. The case studies, which span teachers from four of the five appropriation profiles, seem to confirm the insights from the group-level analysis regarding the influences of context. The reflections of teachers integrating CT after the STIG^{CT} also show that context had an overarching influence over the processes of planning and implementing CT-integrated lessons.

Context Looms over CT Integration

Grossman et al. (1999) mention social context as a factor that can *prevent* teachers from appropriating a pedagogical tool at a higher level. While social context was not always a prohibitive factor, this dissertation suggests that it *did* play a major role in how teachers appropriated CT for their science instruction.

The case studies suggest that teachers' ability to plan and implement CT lessons were impacted by the level of control they had over the curriculum, the level of support for lesson planning they had available, the academic level of their students, and whether technology was available in the school. These factors resonate with the contextual influences that impacted appropriation of CT during the STIG^{CT}.

For example, teachers who appropriated CT Labels were, like Anna and Dakota, constrained by schools that prescribed science lessons and allowed for little flexibility. Other teachers who appropriated CT Labels during the STIG^{CT} cited concerns about developmental appropriateness and believed that certain CT practices were too advanced for their students. These sentiments echo the experience of Ella after the STIG^{CT}, who felt like her students needed to learn CT "pre-requisites" before engaging in programming activities.

However, in the case where these constraints were less pressing, teachers were able to progress on their CT integration. Bridget's case shows an example of a teacher who had support in lesson planning, technology available in her school, and believed her students could (and should) engage in CT practices like programming. She was able to integrate those practices and create new opportunities for CT as well.

Overall, the two analyses demonstrate that CT appropriation *requires* a context supportive of CT integration. However strong a teachers' personal beliefs or conceptual understanding of CT, those factors could only impact lesson planning and implementation when the context was conducive to CT integration in the first place. As explained in Chapters 4 and 5, this finding has implications for teacher education and professional development. Specifically, PD designers should consider how the skills teachers develop around CT integration fit within their existing school contexts.

New models of CT integration should move away from conceptualizing teachers' integration as a function of their understanding of CT and personal beliefs (see Sherwood et al., 2020 for an example). Instead, they should contextualize those factors and understand how lesson planning support, technology availability, and curricular flexibility impact the opportunities for integration teachers can implement. Moreover, the fact that multiple teachers changed schools or positions after their STIG^{CT} participation suggests that PD designers could also aim to provide teachers with resources to navigate CT integration in *multiple* contexts.

The role of Conceptual Understanding

While this dissertation illuminated the strong influence context has on CT integration, it also refines the role of conceptual understanding on CT appropriation. Specifically, this study suggests that the importance of teachers' conceptualization does not lie *only* on defining its boundaries but also on understanding its goals. In Grossman et al.'s framework, the goals of CT could be considered the "conceptual underpinnings" that a teacher needs to understand to reach the Conceptual level of appropriation.

During the PD, conceptual understanding did not demonstrate a clear relationship to teachers' appropriation styles. When looking within profiles, there were no clear patterns of conceptual understanding of the definition of CT. For example, teachers who appropriated CT Labels showed different conceptualizations of CT, and teachers who integrated simulations often had questions about CT and did not demonstrate a unified definition of CT.

The *one* case where a teacher did reach the conceptual level of appropriation, however, demonstrated a different type of conceptualization of *the goals* of CT integration, which may have made the difference between reaching that Conceptual level and staying at the Surface level. Specifically, Ella showed an understanding of CT practices as *central* to her science lesson, not an extension of it. This positioning of CT as central and instrumental to science learning was different than the rest of the lessons teachers designed in the STIG^{CT}.

This perspective of CT *in the service of science* was also evident in Bridget's evolution after the STIG^{CT}. One of her new lessons, which integrated programming practices as her STIG^{CT} lesson had, presented a tighter connection between the CT practices and science learning. These findings suggest that

PD designers need to pay attention to how teachers position CT in their classroom instruction. Perhaps because of the multiple debates on the definition of CT, it is easy to fall into extensive conversations of its boundaries or what kinds of activities truly represent CT engagement. However, this dissertation suggests that, to reach the Conceptual level of appropriation, teachers need to have a particular understanding of how CT can support scientific learning. Of course, this statement is true for perspectives of CT that believe its role *should* be to support disciplinary learning. PD programs with a different view on CT's goals could instead aim to communicate *their own* perspective on the goals of CT to teachers. Either way, this study suggests that the important conceptualizations of CT that impact appropriation not only include its definitions but also its goals.

But, the boundaries of the definition of CT were *also* important in impacting the integration of CT. The fact that, in the year after the STIG^{CT}, teachers' conceptualization of CT seemed to become more generalized, also has implications for the study of CT in teacher education. This generalized perspective impacted the kinds of activities they integrated into their lessons and how they interacted with students. Particularly, teachers made implementation decisions based on their view of CT to engage their students in CT.

These implementation decisions seem to match a view of CT as a type of logical problem-solving, and they are most often distanced from computing concepts. As Ella described it, they reflect "how we want students to learn. Period." While this type of questioning and language use can be productive for students, it is unclear whether implementing CT as a type of thinking without a clear connection to computing would provide students with the foundational understanding of computing that CT integration intends to provide.

Lingering Questions & Limitations

As a study of teachers' integration of CT into elementary science, this work is unable to answer important questions. For instance, while I make suggestions on how PD designers could *aim* to impact factors of the social context of teachers, the ability of PD to actually change those factors remains unknown. Future studies could systematically investigate strategies that promote integration in schools by impacting factors beyond teacher knowledge and beliefs.

Importantly, this study found that teachers who appropriated CT in similar ways had certain patterns of understanding, personal characteristics, and social contexts. It also showed that those characteristics seem to influence their ability to continue integrating CT after their participation in PD. However, I cannot demonstrate a causal relationship—I cannot determine that each particular combination of factors *made* teachers appropriate in the way of their profile. Nevertheless, the commonalities across profiles and teachers suggest that there is some association between how teachers understand CT, the beliefs they hold, how much their context supports CT integration, and how they appropriate CT. Future studies could further investigate the role of interventions aimed at changing each of these factors in a specific direction and their impact on teachers' appropriation of CT.

Another limitation on this study comes from the global context under which the second phase of the study—the case study interviews—were conducted. The interviews took virtually place in the Summer of 2020, as the COVID-19 pandemic continued to severely impact everyone's lives. Teachers in this study had transitioned to Emergency Remote Learning in March of 2020, a few months before the interviews took place. While the lessons integrated and discussed during the interviews all took place during in-person school, it is possible that the pandemic influenced how teachers recalled and reflected on those instances. For example, some teachers, when imagining future CT integration, were discouraged from thinking of using robots or other tactile tools.

Finally, while this study focuses on how teachers appropriate CT, all stakeholders in education research ultimately care about student learning. These profiles are described as different ways of integrating CT, but a higher or different level of appropriation does not necessarily mean that students will learn CT better or more. Future studies should focus on understanding the relationship between how teachers integrate CT in their classroom and the impact such types of appropriation have on student learning.

Chapter 7: Conclusion

This dissertation study found that teachers appropriated (Grossman et al., 1999) CT after the STIG^{CT} mostly at the Labels and Surface levels, with one teacher reaching the Conceptual level. It also shows that, following their PD participation, teachers mostly maintained their appropriation level, with one case severely regressing on it.

However, the study's main contribution is towards our understanding of how teachers' conceptualization of CT, personal characteristics, and social context influence the process of appropriation. Particularly, it shows that social context can be an overarching influence and can hinder or promote CT integration. Both in the STIG^{CT} and after, teacher's availability of support for lesson planning, technology, and curricular flexibility greatly dictated how they were able to integrate CT.

The study also suggests a role for personal characteristics, where apprehension towards programming practices can prevent teachers from integrating those kinds of activities. However, it also found that certain beliefs can override those fears and encourage teachers to integrate programming activities regardless of their confidence level with them.

In terms of conceptual understanding, this study demonstrates that how teachers define *the goals* of CT integration can play an important role in how they integrate it into their lessons. Specifically, the difference between reaching the Conceptual level and Surface level of appropriation was based on whether a teacher adopted the view of CT as a way of supporting scientific learning.

The findings of this study suggest a model of PD around CT that (a) addresses context as a major factor impacting integration into instruction; (b) attends to teachers' conceptualizations of CT beyond definitions to include its purposes and goals; and (c) promotes personal characteristics that can overcome deficits in comfort or confidence with CT practices.

Appendices

Appendix A: Survey

Hello and thank you for taking the time to take this survey.

We are interested in knowing your opinion on computational thinking and education. We want to remind you that your answers will have **NO** effect on your class grade, assignments, or any academic affairs.

Please answer all questions honestly, we really want to hear your opinion!

Let's start with some practice questions.

The following form lists different activities. **Rate how confident you are that you can do them as of now.** Rate your degree of **confidence** by recording a number from 0 to 100 using the scale given below:

0 10 20 30 40 50 60 70 80 90 100

Lifting a 3 pound object ()	
Lifting a 50 pound object ()	
Lifting a 15 pound object ()	
Lifting a 300 pound object ()	

Now that you're familiar with the type of question, let's move on to the next section.

The following form lists different activities. **Rate how confident you are that you can do them as of now.** Rate your degree of **confidence** by recording a number from 0 to 100 using the scale given below:

	Definitely cannot do Definitely can do 0 10 20 30 40 50 60 70 80 90 100
Defining computational thinking practices	
Identifying a computational thinking practice in an educational science activity	
Adapting an existing science lesson to include computational thinking	
Creating an original science lesson that includes computational thinking	
Engaging students in computational thinking during science instruction	
Answering student questions regarding computational thinking activities	
Finding resources to facilitate my integration of computational thinking into science teaching	
Teaching colleagues how to include computational thinking into their science teaching	

End of Block: Default Question Block

Start of Block: Block 1

For the following statements, select your level of agreement on the scale from Strongly Disagree to Strongly Agree.

Computational thinking is important for elementary science education.

- Strongly Disagree (1)
- Disagree (2)
- Slightly Disagree (3)
- Slightly Agree (4)
- Agree (5)
- Strongly Agree (6)

A student’s computational thinking skills are not important to his/her success in elementary science classes

- Strongly Disagree (1)
- Disagree (2)
- Slightly Disagree (3)
- Slightly Agree (4)
- Agree (5)
- Strongly Agree (6)

Science learning activities that include computational thinking increase student interest in STEM, including for students previously uninterested in STEM.

- Strongly Disagree (1)
- Disagree (2)
- Slightly Disagree (3)
- Slightly Agree (4)
- Agree (5)
- Strongly Agree (6)

STEM professionals use computational thinking in their jobs every day.

- Strongly Disagree (1)
- Disagree (2)
- Slightly Disagree (3)
- Slightly Agree (4)
- Agree (5)
- Strongly Agree (6)

Opportunities to engage in computational thinking are important for getting students interested in pursuing STEM careers.

- Strongly Disagree (1)
- Disagree (2)
- Slightly Disagree (3)
- Slightly Agree (4)
- Agree (5)
- Strongly Agree (6)

It is important for students to become aware of STEM careers at the elementary level.

- Strongly Disagree (1)
- Disagree (2)
- Slightly Disagree (3)
- Slightly Agree (4)
- Agree (5)
- Strongly Agree (6)

Future careers in STEM are a possibility for all of my students.

- Strongly Disagree (1)
- Disagree (2)
- Slightly Disagree (3)
- Slightly Agree (4)
- Agree (5)
- Strongly Agree (6)

I am confident in my ability to increase my students' awareness of STEM careers.

- Strongly Disagree (1)
- Disagree (2)
- Slightly Disagree (3)
- Slightly Agree (4)
- Agree (5)
- Strongly Agree (6)

End of Block: Block 2

Start of Block: Block 3

For the following statements, select your level of agreement on the scale from Strongly Disagree to Strongly Agree.

My mentor teacher/resident supports the integration of computational thinking into science instruction in my classroom.

- Strongly Disagree (1)
- Disagree (2)
- Slightly Disagree (3)
- Slightly Agree (4)
- Agree (5)
- Strongly Agree (6)

My school's administration supports the integration of computational thinking into science instruction in my classroom.

- Strongly Disagree (1)
- Disagree (2)
- Slightly Disagree (3)
- Slightly Agree (4)
- Agree (5)
- Strongly Agree (6)

My county's science curriculum supports the integration of computational thinking into science instruction in my classroom.

- Strongly Disagree (1)
- Disagree (2)
- Slightly Disagree (3)
- Slightly Agree (4)
- Agree (5)
- Strongly Agree (6)

The way science is taught in my school supports the integration of computational thinking into science instruction in my classroom.

- Strongly Disagree (1)
- Disagree (2)
- Slightly Disagree (3)
- Slightly Agree (4)
- Agree (5)
- Strongly Agree (6)

The way science is taught at my grade level supports the integration of computational thinking into science instruction in my classroom.

- Strongly Disagree (1)
- Disagree (2)
- Slightly Disagree (3)
- Slightly Agree (4)
- Agree (5)
- Strongly Agree (6)

Full Name

____

Gender

- Male (1)
- Female (2)
- Other (3)
- Prefer not to say (4)

Year of birth

▼ 2018 (1) ... 1930 (89)

Race/Ethnicity (Select all that apply)

1. White (1)
2. Black or African American (2)
3. American Indian or Alaska Native (3)
4. Asian (4)
5. Native Hawaiian or Pacific Islander (5)
6. Hispanic / Latinx (6)
7. Other (7)
8. Prefer not to say (8)

Including this year, how many years have you taught at the elementary level?

____

What grade level(s) are you teaching this year?

1. 1st (1)
2. 2nd (2)
3. 3rd (3)
4. 4th (4)
5. 5th (5)

Appendix B: Vignettes

FEBRURARY = Living Beings.

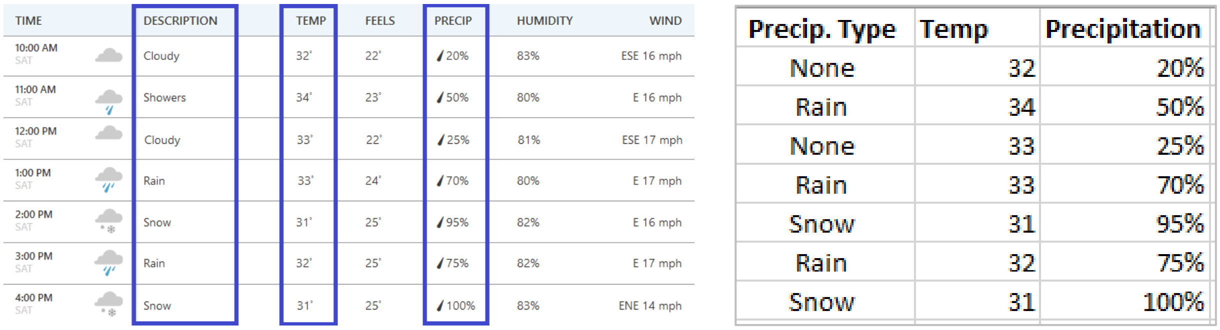
Ms. Smith planned a lesson for her 3rd grade students to learn about living beings. The first part entailed going outside and observing plants and animals such as squirrels and birds. Students wrote their observations on a notepad, where they had two tables: one for "living" and one for "non-living". Ms. Smith asked students to look at some rocks with moss and ask them if either of them was alive. Some students said yes, and others said no.

Predict Precip. Type	Temp (F)	Precipitation Probability
None	25	48%
Rain	34	82%
Snow	30	60%
	35	20%
	32	50%

When they returned to the classroom, Ms. Smith asked the students who believed the moss was alive to show their thinking. Then, she asked students to look at their "living" column and make a list of all things that living beings have in common. Then, Ms. Smith and the students came up with a set of questions that had to be answered one by one to determine if something was alive. For example, they asked: Does it need food? Does it grow? Does it reproduce? The class tried out a few examples (a rock, a bee, and an apple) and only put things in the "living" category if all questions were answered with "yes". Then, each student drew a picture of their favorite living thing and nonliving thing, explaining why each of them was alive or not.

MARCH = Weather Data

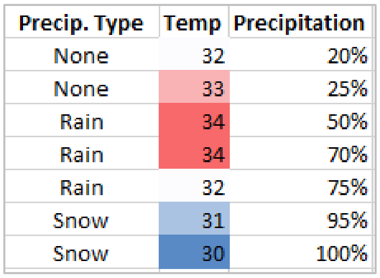
Ms. Nowak designed a lesson for students to understand the relationships between precipitation and temperature. She asked students to use predictions from Weather.com to enter data into an Excel chart (Figure 1).



TIME		DESCRIPTION	TEMP	FEELS	PRECIP	HUMIDITY	WIND
10:00 AM SAT		Cloudy	32°	22°	20%	83%	ESE 16 mph
11:00 AM SAT		Showers	34°	23°	50%	80%	E 16 mph
12:00 PM SAT		Cloudy	33°	22°	25%	81%	ESE 17 mph
1:00 PM SAT		Rain	33°	24°	70%	80%	E 17 mph
2:00 PM SAT		Snow	31°	25°	95%	82%	E 16 mph
3:00 PM SAT		Rain	32°	25°	75%	82%	E 17 mph
4:00 PM SAT		Snow	31°	25°	100%	83%	ENE 14 mph

Precip. Type	Temp	Precipitation
None	32	20%
Rain	34	50%
None	33	25%
Rain	33	70%
Snow	31	95%
Rain	32	75%
Snow	31	100%

Figure 1. Students used information from Weather.com (pictured left) to enter data into an Excel chart (pictured right)



Precip. Type	Temp	Precipitation
None	32	20%
None	33	25%
Rain	34	50%
Rain	34	70%
Rain	32	75%
Snow	31	95%
Snow	30	100%

Ms. Nowak asked the students, *what do you notice about the temperature when the scientists predict rains versus when it snows?* To answer this question, the students used Excel to group the times that rain or snow was predicted. They represented warmer or cooler temperatures with different colors (Figure 2). The students explained how every time snow was predicted, the temperature was below 32 degrees, which is the temperature where water freezes!

Finally, Ms. Nowak asked the students to consider the probability that it would precipitate. She asked students, *out of all the days when scientists predicted* ***snow or rain****, what was the* ***lowest*** *precipitation probability?* Using data from the spreadsheet, students identified 50% as the lowest value. Ms. Nowak then asked students to predict whether it would rain, snow, or neither given the temperature and precipitation probability by completing the chart below. Students then discussed their predictions.

APRIL = Pollination simulation.

Mr. Benjamin is teaching his 2nd grade class about pollination. He wants his students to understand that some plants use pollinators, such as bees, to reproduce. First, Mr. Benjamin shows his students a video where a scientist shows footage of bees entering multiple flowers while she explains the process of pollination.

Then, Mr. Benjamin asks the students, "how do you think pollen sticks to the bee's body?". To explore possible explanations, the students design "pollen collectors." Students are provided several materials: carpet, sponge, plastic, paper (to represent the bee's body) and a container of wet sand (to represent the flower/pollen). Each group tests how much "pollen" each material collects. They discuss results as a class. Mr. Benjamin then explains the similarities between these materials, the bodies of bees, and the stickiness of pollen.

The next day, Mr. Benjamin asks the students to engage in a simulation activity about the process of pollination. In the activity, each student is assigned a role as a flower, pollen or bee. When a child playing a bee visits a child representing a flower, another child representing pollen will now follow the "bee" anywhere it goes until it visits another flower. The goal of each group of "bees" is to get each "pollen" to as many different "flowers" as they can. Finally, Mr. Benjamin explains how the activity is like the way bees behave in the world—the bees are not *trying* to pollinate trees; they just happen to do so while they feed on the flowers.

MAY = Energy Scratch.

Ms. Spring is teaching her 5th grade class about energy. Her goal is for students to understand that energy in animals' food was once energy from the sun. Ms. Spring's students generally know that plants, through photosynthesis, create glucose (sugar), which is used by cells. They also know that some animals eat plants, and that other animals eat smaller prey. But, she wants students to understand the big picture; the connection from the sun to the carnivore.

To reinforce the idea that energy in animals' food was once energy from the sun, Ms. Spring has students use Scratch to create a story that shows how energy is converted in each step. The story must start with the sun, have 1 or 2 energy conversions, and end in an animal eating another animal. The students create their stories by programming animations that represent the conversion of energy.

Ms. Spring uses the stories to assess the students understanding. For example, she notices that Timmy created a story where the sun heated up a fish that a bird was eating, and Timmy said that it was that heat energy that is absorbed by the animal. Ms. Spring uses this opportunity to talk to the class about the differences between energy from heat and energy from food.

Appendix C: Lesson Seed Reflection

Lesson Seed Think-Pair Share

1. How do you get started with the lesson seed?

2. How have different group members (mentor teachers, residents, CT team members) contributed to your lesson seed planning?

3. What has been challenging about lesson seed planning?

4. What has been helpful?

5. What resources would be even more helpful?

Appendix D: Lesson Seed Template

Part 1: Computational Thinking-Infused Elementary Science Lesson Seed

Directions: Complete the lesson seed by answering questions #1-3 below during the workshop in your small groups. You will complete a lesson seed during workshops in Feb, Mar and Apr. One time this semester, you are expected to build on the lesson seed to develop a lesson plan that you teach to your class. For this lesson, you should also complete Part 2.

1. ***Describe the objective(s) of the lesson.***

2) ***Describe the instructional procedures for your computational thinking-infused elementary science lesson (use back for more space).***

3) ***Identify the computational thinking practice(s) in the lesson:***

Using data

- ☐Finding patterns and relationships in datasets
- ☐Sorting data
- ☐Creating graphs or charts

Computational Simulations

- ☐Using computational simulations
- ☐Assessing computational simulations

Programming

- ☐Breaking down problems into smaller parts
- ☐Creating step-by-step instructions to solve a problem
- ☐Coding
- ☐Test, Adjust to improve, Retest, Readjust to improve

Computational Systems Thinking

- ☐Identifying quantifiable parts of a system
- ☐Considering numerical relationships within a system
- ☐Considering how changes to the quantifiable parts contribute to results of the system

Appendix E: Focus Group Protocols

Non-STIG Resident interview

1. Have you seen or heard about CT in your other courses or elsewhere?

2. Have you had a discussion about CT with your mentor teacher?
    - Do they support the integration of CT?
        - *Probe (if not addressed):* How?
        - *Probe (if not addressed):* Why?

3. How have the learning experiences we've provided influenced your ideas about CT in the classroom?
    - What was useful? What activities?
    - What could be changed (add or removed) to make it more useful?

4. How comfortable are you integrating CT in an elementary science lesson?

5. Have you integrated CT in your classroom since the course?

    IF THE ANSWER TO #5 IS ***YES*** *- READ THESE QUESTIONS*
    - How often have you integrated CT in your science classroom?
    - How can CT change the way your students engage in science learning?
    - Did you also integrate CT in other subjects? If so, which ones and how often?
    - How did you integrate CT in your classroom? (*use the framework here for reference)*
        - Why did you integrate CT?
            - Probe (if not addressed) what are the benefits are integrating computational thinking
            - Probe (if used a CT tool) - how did you use that tool? How does that tool allow students to engage in CT?
        - What were the challenges of integrating CT?
            - Probe: Are there some CT practices that are more challenging than others for elementary learners? (*use the framework here for reference)*
        - Describe how students reacted to the integration of CT.
        - If/how was your mentor teacher involved in the integration of CT?

    IF THE ANSWER TO #5 IS ***NO*** *- READ THESE QUESTIONS*
    - Why have you not integrated CT?
        - *Probe (if not addressed):* What are the challenges?
        - Are there some CT practices that are less challenging than others for elementary learners? (*use the framework here for reference)*

STIG Resident interview

6. Have you seen or heard about CT aside from TLPL321 and the STIG?

7. Have you had a discussion about CT with your mentor teacher?
    - Do they support the integration of CT?
        - *Probe (if not addressed):* How?
        - *Probe (if not addressed):* Why?

8. How have the learning experiences we've provided influenced your ideas about CT in the classroom?
    - What was useful? What activities?
    - What could be changed (add or removed) to make it more useful?

9. How comfortable are you integrating CT in an elementary science lesson?

10. Have you integrated CT in your classroom since the course?

    *IF THE ANSWER TO #10 IS **YES** - READ THESE QUESTIONS*
    - How often have you integrated CT in your science classroom?
    - How can CT change the way your students engage in science learning?
    - Did you also integrate CT in other subjects? If so, which ones and how often?
    - How did you integrate CT in your classroom? (*use the framework here for reference)*
        - Why did you integrate CT?
            - Probe (if not addressed) what are the benefits of integrating computational thinking
            - Probe (if used a CT tool) - how did you use that tool? How does that tool allow students to engage in CT?
        - What were the challenges of integrating CT?
            - Probe: Are there some CT practices that are more challenging than others for elementary learners? (*use the framework here for reference)*
        - Describe how students reacted to the integration of CT.
        - If/how was your mentor teacher involved in the integration of CT?

    *IF THE ANSWER TO #5 IS **NO** - READ THESE QUESTIONS*
    - Why have you not integrated CT?
        - *Probe (if not addressed):* What are the challenges?
        - Are there some CT practices that are less challenging than others for elementary learners? (*use the framework here for reference)*

Returning Resident Interview

11. Have you seen, heard or discussed computational thinking outside of this group?
    - *Probe (if yes): Tell me more: With who? Where? What did you talk about?*

12. Thinking of your last two years of participation, how have the learning experiences we've provided influenced your ideas about CT in the classroom?
    - What was useful? What activities?
    - What could be changed (add or removed) to make it more useful?

13. Has your experience this year been different than last year?
    - *Probe (if yes): Tell me more: how?*

14. How comfortable are you integrating CT in an elementary science lesson?

15. Have you integrated CT in your classroom?

    *IF THE ANSWER TO #5 IS **YES** - READ THESE QUESTIONS*
    - How often have you integrated CT in your science classroom?
    - How can CT change the way your students engage in science learning?
    - Did you also integrate CT in other subjects? If so, which ones and how often?
    - How did you integrate CT in your classroom? (*use the framework here for reference)*
        - Why did you integrate CT?
            - Probe (if not addressed) what are the benefits of integrating computational thinking
            - Probe (if used a CT tool) - how did you use that tool? How does that tool allow students to engage in CT?
        - What were the challenges of integrating CT?
            - Probe: Are there some CT practices that are more challenging than others for elementary learners? (*use the framework here for reference)*

        - Describe how students reacted to the integration of CT.
        - If/how was your mentor teacher involved in the integration of CT?

IF THE ANSWER TO #5 IS ***NO*** *- READ THESE QUESTIONS*

- Why have you not integrated CT?
    - *Probe (if not addressed):* What are the challenges?
    - Are there some CT practices that are less challenging than others for elementary learners? (*use the framework here for reference)*

Mentor Teacher Interview

16. Have you seen, heard or discussed computational thinking outside of this group?
    - *Probe (if yes): Tell me more: With who? Where? What did you talk about?*

17. How have the learning experiences we've provided influenced your ideas about CT in the classroom?
    - What was useful? What activities?
    - What could be changed (add or removed) to make it more useful?

18. How comfortable are you integrating CT in an elementary science lesson?

19. Have you integrated CT in your classroom?

IF THE ANSWER TO #5 IS ***YES*** *- READ THESE QUESTIONS*

- How often have you integrated CT in your science classroom?
- How can CT change the way your students engage in science learning?
- Did you also integrate CT in other subjects? If so, which ones and how often?
- How did you integrate CT in your classroom? (*use the framework here for reference)*
    - Why did you integrate CT?
        - Probe (if not addressed) what are the benefits are integrating computational thinking
        - Probe (if used a CT tool) - how did you use that tool? How does that tool allow students to engage in CT?
    - What were the challenges of integrating CT?
        - Probe: Are there some CT practices that are more challenging than others for elementary learners? (*use the framework here for reference)*
    - Describe how students reacted to the integration of CT.
    - If/how was your mentor teacher involved in the integration of CT?

IF THE ANSWER TO #5 IS ***NO*** *- READ THESE QUESTIONS*

- Why have you not integrated CT?
    - *Probe (if not addressed):* What are the challenges?
    - Are there some CT practices that are less challenging than others for elementary learners? (*use the framework here for reference)*

Returning Mentor Teacher Interview

20. Have you seen, heard or discussed computational thinking outside of this group?
    - *Probe (if yes): Tell me more: With who? Where? What did you talk about?*

21. Thinking of your last two years of participation, how have the learning experiences we've provided influenced your ideas about CT in the classroom?

- What was useful? What activities?
- What could be changed (add or removed) to make it more useful?

22. Has your experience this year been different than last year?
    - *Probe (if yes): Tell me more: how?*

23. How comfortable are you integrating CT in an elementary science lesson?

24. Have you integrated CT in your classroom?

IF THE ANSWER TO #5 IS ***YES*** *- READ THESE QUESTIONS*

- How often have you integrated CT in your science classroom?
- How can CT change the way your students engage in science learning?
- Did you also integrate CT in other subjects? If so, which ones and how often?
- How did you integrate CT in your classroom? (*use the framework here for reference)*
  - Why did you integrate CT?
    - Probe (if not addressed) what are the benefits are integrating computational thinking
    - Probe (if used a CT tool) - how did you use that tool? How does that tool allow students to engage in CT?
  - What were the challenges of integrating CT?
    - Probe: Are there some CT practices that are more challenging than others for elementary learners? (*use the framework here for reference)*
  - Describe how students reacted to the integration of CT.
  - If/how was your mentor teacher involved in the integration of CT?

IF THE ANSWER TO #5 IS ***NO*** *- READ THESE QUESTIONS*

- Why have you not integrated CT?
  - *Probe (if not addressed):* What are the challenges?

Are there some CT practices that are less challenging than others for elementary learners? (*use the framework here for reference)*

Appendix F: Lesson Plan Template

Part 2: Computational Thinking-Infused Elementary Science Lesson Plan & Reflection

Directions: ONE TIME THIS SEMESTER, you should build on Part 1 to develop a lesson plan that you teach to your class. For this lesson, you should complete questions #1-5 below.

1) ***Describe, in as much detail as a carefully designed lesson plan, the instructional procedures for the computational thinking-infused elementary science lesson you completed in your classroom*** *(Note: It is okay to be modify from your lesson seed in Part 1).*

2) ***What did your students learn (or not learn) about science? How do you know (what did the students say and/or do)?*** *(Note: Be specific. For instance, you may write down anonymous student quotes, transcribe anonymous student work or describe specific actions of anonymous students during class).*

3) ***What did your students learn (or not learn) about CT? How do you know (what did the students say and/or do)?*** *(Note: Be specific. For instance, you may write down anonymous student quotes, transcribe anonymous student work or describe specific actions of anonymous students during class).*

4) ***Did you see evidence that some students in your class were more engaged or successful than others? If so, please explain.*** *(Note: Be specific. For instance, you may write down anonymous student quotes, transcribe anonymous student work or describe specific actions of anonymous students during class).*

5) ***What would you do the same and what would you do differently next time for this lesson? Why?***

Appendix G: General integration and reflection interview

This protocol will be used to guide a semi-structured interview. The following questions are aimed at eliciting the participant's views about computational thinking (CT) implementation in the elementary classroom, their ideas on how CT could be adapted to online environments, and other aspects of teaching online. Because this interview will be semi-structured, the questions are used as a guide—other questions or topics may arise during the conversation, and the researcher is free to ask the participant to elaborate on her answers.

Follow-up questions:

Hello, welcome and thank you for participating in our follow-up interview. We've invited you to participate because you have participated in our Science Teaching Inquiry Group for Computational Thinking (STIG^{CT}) in the Spring of 2019. Before we begin, please read over the consent form and let me know if you have any questions about consent.

[After and only if participant has consented to participate, begin the interview]

Just so you know, I've started the recording of the meeting. We have a few sets of different questions to go over, but these questions are meant to be an overall guide to our conversation—we do not need to cover all of them. You can also choose to skip any question you do not want to answer, without affecting your participation in the study. Whenever you're ready, we can start. [When participant agrees, begin questioning]

Introduction

- Where have you taught in the **last year**? (County/School)
- What grades have you been teaching?
- Have you been teaching science?

CT Implementation questions

1) **It's been approximately a year since we had our last STIG session. Have you been able to implement CT in your teaching in the last year?**
    a) If so, how so?
        i) What made you think to integrate CT?
        ii) Tell me about how you came up with the lesson(s) plan(s) that infused CT
        iii) What science topic(s) did you integrate CT into, and why?
        iv) Tell me about the lesson(s) that integrated CT. What practices did you integrate?
        v) How did the lessons go? Do you think your children engaged in CT?
        vi) How were you able to assess your students' learning about CT or science?
    b) If not, what do you think are the reasons you were not able to?
        i) How would you have liked to integrate CT?
        ii) What obstacles did you face?
        iii) What do you think would be necessary for you to integrate CT in the future in face-to-face classes?

Appendix H: Lesson Design Interview

This protocol will be used to guide a semi-structured interview. The following questions are aimed at eliciting the participant's views about computational thinking (CT) implementation in the elementary classroom, their ideas on how CT could be adapted to online environments, and other aspects of teaching online. Because this interview will be semi-structured, the questions are used as a guide—other questions or topics may arise during the conversation, and the researcher is free to ask the participant to elaborate on her answers.

Hello, welcome and thank you for participating in our follow-up interview. We've invited you to participate because you have participated in our Science Teaching Inquiry Group for Computational Thinking (STIG^{CT}) in the Spring of 2019. Before we begin, please read over the consent form and let me know if you have any questions about consent.

[After and only if participant has consented to participate, begin the interview]

[PRESS RECORD BUTTON]

Just so you know, I've started the recording of the meeting. We have a few sets of different questions to go over, but these questions are meant to be an overall guide to our conversation—we do not need to cover all of them. You can also choose to skip any question you do not want to answer, without affecting your participation in the study. Whenever you're ready, we can start. [When participant agrees, begin questioning]

This interview is aimed at gaining a more detailed understanding of the process of planning a CT-infused science lesson. You mentioned in your last interview that you had the opportunity to integrate CT in the last year, and we've asked you to retrieve the lesson plan(s) of those instances if you still have them available. We want to know more about your process for planning the integration pf CT practices in those lesson plans.

1. First, can you remind us of the times that you integrated CT in the last year?
    a. Do you have the final lesson plan(s) for us to look at?

If participant has multiple lessons, then choose 2 lessons to discuss based on:

a. Which lesson do you think was the one with the most CT practices infused?
b. Which lesson do you think was most successful in engaging children in CT?
    a. If both answers are same lesson, choose a "second best" for either category

[Pick Instance A]

We want to understand the process of planning for CT integration.

2. Can you describe the lesson *plan*? If you still have it, can we look at it together?
    [Read lesson plan together or take notes of the description, use this information to reference throughout interview]
3. How did you create this lesson plan?
    a. Did you base the lesson on an existing lesson?
    b. Where did that original lesson come from?
    c. Why did you use this original lesson as a starting point?
    d. What gave you the idea to start a lesson from scratch?
4. What were your goals when *designing* the lesson?
    a. What did you want your kids to learn?
    b. What did you want your students to achieve?
5. Which science topic did you integrate CT on?
    a. Why did you choose this topic/unit as a context for CT integration?

    b. Were there any curricular standards you were trying to meet?
        i. How do you think CT could help students meet those standards?
6. Tell me about your decision to integrate CT, which CT practices did you integrate?
    a. Which activities did you design or adapt that engaged children in CT?
    b. How did you come up with those activities?
    c. Did you use any resources to come up with the activities?
7. Did you include any assessment of student understanding in this lesson?
    a. How did you assess understanding?
8. Did you take into account any student prior knowledge or potential misconceptions when designing this lesson?
    a. If so, please elaborate on those considerations.
9. Are there other factors that played a role in your planning of the lesson?
    a. Were there any implementation challenges you envisioned when planning the lesson?
        i. How did you try to address those challenges?
    b. Were there any parts of the lesson that you felt more comfortable planning for than others?
    c. Were there any parts of the lesson that you struggled to plan?
    d. How long did you plan the lesson to be?
    e. How did you estimate the time it would take for each activity in the lesson?
10. Were there any other CT practices that you wanted to integrate but were not able to include in the lesson plan? *(To clarify, we're talking about* ***planning*** *here,* ***not*** *practices you planned for but weren't able to integrate during the implementation)*
    a. What were the challenges of planning the integration of those practices?

[Pick instance B and go through questions 2-10 again]

11. *Now that we've talked about how you designed lessons in the past, I'd like to know a little about how you could plan in the future*. If you were to plan a new CT lesson, how would you go about it?

Wonderful, thank you for going into detail about your planning with me. Are there any other general comments about planning to integrate CT that you would like to share with us?

Thank you for participating in this second interview! As a reminder, we have one more interview to go, which will focus on your teaching of the lessons we discussed today. We look forward to seeing you then.

[If necessary, schedule the second and last interview]

Appendix I: Implementation Interview

This protocol will be used to guide a semi-structured interview. The following questions are aimed at eliciting the participant's views about computational thinking (CT) implementation in the elementary classroom. Because this interview will be semi-structured, the questions are used as a guide—other questions or topics may arise during the conversation, and the researcher is free to ask the participant to elaborate on her answers.

This interview is aimed at gaining a more detailed understanding of the process of teaching a CT-infused science lesson. In the last interview, we discussed how you planned the lesson(s) where you integrated CT. Today, we'll focus on the teaching of those lessons. Specifically, we want to know more about decisions you made during implementation and how students reacted as they went through the lesson. Before we being, do you have any questions? [Answer any questions from participant]

[PRESS RECORD BUTTON]

[Pick Instance A from previous interview on planning]

1. Let's review the lesson plan we discussed last time we met. We want to know more about how you taught this lesson and how students reacted during it. So, we'll walk through the plan and talk about each part. [Use either lesson plan shared or notes from Interview 2 to reference]
2. *For each part of the lesson or activity, ask these questions:*
   How would you say this part went?
    a. How did you explain or frame this activity for students?
    b. How did they react?
        i. Did you see students engage in the activity as you envisioned?
        ii. Did some students react or act differently? How so?
        iii. If so, why do you think those students had a different course of action?
    c. What do you think students were successful at doing during this activity?
        i. *If necessary, follow up to understand the* ***evidence*** *the teacher has to believe students succeeded at a task.*
    d. What do you think students struggled with during this activity?
        i. *Again, if necessary, follow up for evidence.*
    e. Did this part of the lesson engage students in CT? *(Be careful not to be leading here, participant should feel okay to say this part did* ***not*** *engage students in CT but others were)*
    f. Do you think the CT helped students learn science content?
        i. How did learning this science topic through CT differ from learning it in previous years or without CT?
    g. How close to the plan do you think you were able to implement this part?
        i. Did anything differ during implementation from the plan?
        ii. What made you make those changes or adaptations?
    h. Is there anything you wish you had done differently for this part of the lesson?
        i. What would you do differently? Why?
        ii. What would you change in how you teach this lesson?
        iii. Would you teach this lesson again?

[Once you finished going over each part of Instance A, pick Instance B and repeat the questions for each part of the lesson]

Thank you for answering those questions! Before we close, do you have any questions for us, the researchers?

Thank you again for participating. *[Stop recording and go over compensation procedures with participant]*

Appendix J: Deductive Codebook

RQ1

A. **Social Context of Learning**
   1. *Admin or Peer Support*—Evidence that administrators or peers were supportive or discouraging of CT integration
   2. *Curriculum Alignment*—Discussions or conversations around how CT fits into existing curriculum and how it could be integrated.
   3. *Resources Available*—Discussions around material and other resources that teachers can use to support their integration of CT

B. **Characteristics of the Learner**
   1. *Self-Efficacy*—The teacher's belief about what she is able to do, how confident she is in her ability to integrate CT into her science teaching.
   2. *Learning Beliefs*—Beliefs about how students learn, including whether students are capable of completing an activity, comprehend a concept, or engage in a CT practice.
   3. *Comfort with Technology*—Teachers discussing their own ability to use technological tools.

C. **Conceptual Understanding**
   1. *CT Definitions*—Discussions or questions around how practices are defined and the boundaries of CT.
   2. *CT Operationalizations*—Discussions or questions about activities that would engage children in CT. This includes both suggesting an activity as CT and asking whether an activity is computational.
   3. *Role of CT in Science—*Discussions around how CT can impact science learning and the relationship between the two concepts.

RQ2

D. **Design**
   1. Comments about the process of designing a lesson plan, such as goals, activities explored, collaboration with peers, assessment of students before lesson.

E. **Implementation**
   1. Comments and narratives about the process of teaching a lesson including teacher-student interactions, decisions made in the classroom, and other instructional situations.

F. **Reflection**
   1. Comments about the results of the lesson, its impact on student learning, and preparation for future CT integration.

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