**Dragons, Squishy Circuits, and Computational Thinking:**
**Integrating Scientific Literacies into Elementary Classrooms**

Computational thinking (CT) is most often defined as the problem-solving practices, concepts, and dispositions that draw on the computer science discipline (CSTA & ISTE, 2011; Wing, 2006). CT involves breaking down complex problems, recognizing patterns, designing algorithms, creating solutions, overcoming obstacles, and collaborating with peers (Kafai et al., 2020). When students come to understand and use CT concepts, skills, and dispositions, they are not just learning how to code, but rather how to think computationally by approaching problems in systematic ways that mirror computer science practices. The Next Generation Science Standards (NGSS Lead States, 2013) include CT as a core scientific practice that, at the elementary level, support students' abilities to collect and analyze data, compare different solutions to complex problems, and engage in the engineering design process.

This article describes the Making CT project, a 3-year researcher-practitioner partnership in which researchers partnered with 14 elementary teachers to design and implement CT-infused lessons that integrated CT concepts, read-alouds, and Making to support content learning goals. First, we argue for envisioning CT as a 21st-century scientific literacy that can and should be connected to disciplinary learning. Then, drawing from a case study analysis of Making CT teachers' lesson design and implementation processes, we provide a practical framework, CT-READ, which was co-developed with teacher partners. Throughout our description of the framework, we utilize a sample case study of Ms. Vernon's fifth-grade classroom in order to illustrate how the model functions in a real-world context. We conclude with lessons learned and concrete strategies to help educators leverage CT to support students' development of content knowledge.

## What is Computational Thinking?

There has been growing interest in how CT can support students' learning across multiple content areas, including science, math, English language arts, and social studies (Rich et al., 2020). While several definitions of CT exist in the literature, the PRADA (Pattern Recognition, Abstraction, Decomposition, and Algorithms) model (Author, 2019) integrates well-established CT concepts (Shute et al., 2017) in a mnemonic device that's accessible for both teachers and students. These concepts represent fundamental principles of computer science (CS), enabling students to use *pattern recognition* to identify repeating patterns, *abstraction* to name and identify higher-level concepts and hide details, *decomposition* to break down problems into manageable parts, and *algorithms* to provide sequential instructions for solving a problem. For example, from a CS perspective, abstraction implies "hiding the details" and is commonly implemented in computer subroutines that hide details (like the "AVERAGE" and "COUNT" functions available in a spreadsheet).

Recent research has demonstrated that CT can provide an authentic and meaningful context for applying new knowledge to real-world problems (Weintrop et al., 2016). When CT instruction is linked to disciplinary learning goals (Israel et al., 2015), students can deepen learning through hands-on engagement and opportunities to solve authentic problems (Grover, 2017). For example, when teaching science content, teachers can use abstraction to help students name scientific processes (e.g., the water cycle), think about the details hidden behind the name, and develop repeatable processes for experimentation (algorithms). Table 1 provides examples of how PRADA can be mapped to science content.

[INSERT TABLE 1 ABOUT HERE]

Emerging research also suggests that CT should be introduced to children in the preschool and elementary grades (Bers, 2017). For young learners, implementing a recursive curriculum using varied strategies (e.g., unplugged lessons, emergent plugged-in coding activities, and problem-solving practices linked to specific disciplines) enables students to explore CT using practices that are both familiar and unfamiliar (Conde et al., 2017). However, in order to successfully infuse CT into their classrooms, teachers need explicit support, guidance, and resources for their students. One challenge is helping teachers to develop deep understandings of CT concepts so that they can be woven in amongst disciplinary content and used to strengthen content area learning opportunities.

## Towards CT as an Essential 21st-Century Scientific Literacy

We envision computational thinking as an essential 21st-century scientific literacy, one that draws on inherent connections between CT and essential disciplinary practices in science—including using careful observation to develop interpretations, "using high-level reasoning, applying existing understanding of scientific ideas, and communicating scientific information" (Fang & Wei, 2010, p. 263). This is well-aligned with the goals of disciplinary literacy instruction, which aims to engage students with the types of texts, practices, and goals that are needed in specific disciplines (Shanahan & Shanahan, 2008). Making explicit connections between CT concepts and disciplinary standards can make complex processes more visible as students learn "how to read, write, and reason with the language, texts, and dispositions of science" (Pearson et al., 2010, p. 459). For example, as students come to understand how energy transfers in a circuit, they can use pattern recognition to make sense of multimodal representations, decomposition to identify circuit components, abstraction to give names to components and processes, and algorithms to design their own circuits.

Viewing CT as a scientific literacy also opens new opportunities for designing interdisciplinary learning activities, described in part by Holbrook and Rannikmae (2009) as "connect[ing] science and technology to other human endeavors (e.g., history, mathematics, the arts, and the humanities)" (p. 277). It's important to recognize that the work of designing an interdisciplinary, CT-infused lesson is complex and requires a comprehensive understanding of content learning goals and standards, deep knowledge of CT concepts, and careful consideration of authentic connections among disciplines. Teachers must develop inquiry-based instructional practices that enable students to build new CT and content knowledge and put it into practice (Lee & Malyn-Smith, 2020).

One barrier many teachers face is the challenge of incorporating scientific literacies, including CT, into tightly packed schedules that afford little time for additional activities or subjects (Carrier et al., 2013). One potential solution is to design interdisciplinary learning activities that weave scientific literacy into other subjects, such as ELA. Read-alouds, in particular, can maximize instructional time, connect across disciplines, and make complex content accessible. Previous research has explored how read-alouds can develop students' understanding of science (Heisey & Kucan, 2010) and mathematics concepts (Hintz & Smith, 2013). Heisey and Kucan (2010) found that a crucial element of content-integrated read-alouds is providing students with multiple exposures to a concept, affording students "more time to build a mental representation of important ideas" (p. 675). After selecting high-quality texts, teachers must identify key vocabulary terms, text structures, text features, and parts of the text that will be difficult for students to comprehend (Hoffman et al., 2015). Designing pre-planned supports and scaffolds is especially important for CT-infused read-alouds in order for children's literature to act as a bridge for introducing CT as an important thinking practice that spans disciplines.

Leveraging CT as a scientific literacy also requires the careful design of complementary hands-on investigations. Making is a specific process that tasks learners with solving authentic, interdisciplinary problems using common craft supplies, advanced technological tools, and other artifacts (Author, 2020; Peppler & Bender, 2013; Wohlwend et al., 2017). In their work with the MakEY project, Marsh and colleagues (2018) found that using Maker literacies, which they define as the use of multimodal text analysis, design, and production, can help to make complex STEM concepts more meaningful for young children. CT and Making share many common practices–sustained and interdisciplinary learning, creation in response to authentic problems, and peer collaboration (McLean & Rowsell, 2020; Stornaiuolo et al., 2018; Wohlwend et al., 2017).

The Making CT project brings together Making, CT, and interdisciplinary practices to support teachers in enacting inquiry-based lessons that engage students in interdisciplinary problem-solving. In the next section, we describe the context for the Making CT project, which leverages CT as a core scientific literacy. Then, we illustrate how teachers leveraged pedagogical practices both familiar (read-alouds) and unfamiliar (Making and using computational tools) to help their learners make sense of complex scientific concepts and content.

## The Making CT Project

The Making CT project aims to support teachers in designing and implementing interdisciplinary CT-infused lessons. Participants in this teacher-researcher partnership included 14 teachers from Wakefield Elementary School (school name and all participant names are pseudonyms), as well as the students in their classrooms. Wakefield is located in a suburban area in the Southeastern United States and serves a diverse student population (54% Black, 25% White, 12% Hispanic, 6% two or more races, 2% Asian, and 1% Other), with 100% of students eligible for free or reduced lunch.

**Building a Researcher-Practitioner Partnership**

The authors (research team members) come from different disciplinary backgrounds (literacy education, STEM education, and computer science education), have K-12 classroom teaching experience, and have worked together on several projects focused on CT and interdisciplinary STEM education. Our relationship with Wakefield teachers began before the Making CT project started; three of the 14 teachers were partners on a previous, related project (Author, 2020) in which we co-designed standards-based Making lessons, co-taught lessons, and co-led professional development sessions. As one of the hallmarks of a researcher-practitioner partnership is a commitment to sustaining collaboration across multiple projects (Coburn et al., 2021), these established relationships formed a strong foundation of trust and laid the groundwork for Making CT.

In Spring 2020, Making CT work began with a group of 8 Wakefield teachers. Monthly Making CT collaborative work group sessions (approximately one hour each) were designed to meet multiple learning goals: supporting teachers in developing rich conceptualizations of CT, increasing their self-efficacy in teaching CT- infused lessons, and planning for the design of new lessons and activities. While sessions were initially planned and enacted in a face-to-face format, due to COVID-19 restrictions, we shifted to virtual sessions for the 2020-2021 and 2021-2022 school years. We used digital tools such as breakout rooms and collaborative note-catchers for small-group discussions, developed online repositories of resources, and distributed physical toolkits containing children's books emphasizing various CT concepts and ideas, and workshop materials prior to each session.

Most sessions followed the same algorithm: CT warm-up activities (e.g., creating an algorithm for an everyday activity like lining up for recess), reinforcement of selected CT concepts, abbreviated lessons in which teachers acted as learners, small-group discussions focused on the children's books in the monthly toolkit, and co-planning time. For instance, during the session on Decomposition, Dragons, and Algorithms, we first introduced rubber duck debugging (a popular process in software development for finding and resolving errors), in which the learner explains their thinking during algorithm design to a rubber duck. Then, we read *Dragons Love Tacos* aloud, after which the teachers practiced rubber duck debugging as they wrote algorithms and created Squishy Circuit party favors. They finished the session in small-group breakouts to discuss other texts that can be used to introduce decomposition and algorithms.

Teacher discussion and feedback informed the design of future sessions and the development of CT-infused resources. For example, during a Fall 2020 session, teachers mentioned the need for a concrete visual to take advantage of organic opportunities to highlight CT during read-alouds. Research team members designed an initial draft of a poster with CT concept definitions, and during a follow-up session, teachers helped to refine definitions by putting them in student-friendly language, offered new ideas for the visual components, and suggested making large classroom posters and smaller versions for students to paste into journals (see Figure 1 for final poster). Ms. Janney, a first-grade teacher, described how she planned to use the poster as a reminder of the connections between CT and content learning on a regular basis:

> We always think on our feet--'Oh, this ties in with that element. Oh, we're doing an algorithm right now.' With that in my room as a visual reminder, not only for me but for my kids, we can talk about how those things tie into everyday life.

[INSERT FIGURE 1 ABOUT HERE]

For the 2021-2022 school year, we asked partner teachers to invite colleagues to join Making CT. Our original group of teachers expanded to 14, including 7 of 8 teachers who participated in 2020-2021 and 7 new teachers. Of the 14 teachers, 2 taught 1st grade, 6 taught 2nd, 2 taught 3rd, 1 taught 4th, and 3 taught 5th. Teachers had experience ranging from 1 to 29 years, with an average of 7.3 years of experience. During 2021-2022 monthly sessions, returning teachers had regular opportunities to share expertise in supporting students' CT learning and their experiences in teaching particular lessons.

Through our researcher-practitioner partnership, we have collaboratively created 15 Making CT lessons. Each lesson includes a read-aloud, an anticipation guide, guided discussion questions, a Making activity, and opportunities for students to collaborate and share their work. All lessons and accompanying instructional materials, including assessments, discussion guides, and lists of materials, are freely available to all educators on the project website (removed for manuscript blinding).

**Data Collection and Analysis**

In order to document teacher partners' learning and the process of integrating CT-infused lessons into their classrooms, we interviewed teachers at several points (beginning-of-year, mid-year, end-of-year), surveyed teachers after each monthly session, collected video-recordings of lesson implementation and student artifacts (e.g., photos of Making CT projects, anticipation guides, and graphic organizers), and kept journals documenting our work. After each session, we reviewed teacher surveys and recordings, contacted teachers interested in co-planning, and provided support for revising and enacting lessons.

Our goal for this study was to trace how teachers took up CT-infused pedagogical practices to adapt and design new lessons for their students. We constructed case studies for each teacher (Stake, 2008) in which we documented initial lesson ideas and adaptations, examined teachers' interactions in the monthly sessions, analyzed classroom video, and reviewed teacher reflections and student artifacts. As we compared teachers' pedagogical practices across cases and reviewed research team notes to document our own lesson-planning processes, patterns emerged in relation to the progression of lesson design—identifying content learning goals, selecting texts to introduce or highlight CT concepts, scaffolding read-alouds, designing activities to allow for hands-on Making, and creating closing activities for students to synthesize new knowledge. At this point, we realized it would be helpful to construct a formalized model for planning interdisciplinary, CT-infused lessons, both for future work with Wakefield teachers and for others interested in designing similar lessons.

The result of this analysis is the CT-READ model, described below, which was developed in collaboration with Making CT partner teachers. In order to illustrate how the model functions, we share a case study of Ms. Vernon, a fifth-grade teacher, and her process for conceptualizing, designing, and enacting the Decisions, Dragons, and Decomposition lesson in her classroom. Ms. Vernon joined Making CT in the second year of the project after other members of her grade-level team encouraged her to join. Prior to teaching Decisions, Dragons, and Decomposition, she implemented another CT-infused lesson focused on pattern recognition and algorithms, which she said provided a foundation for her to "dive further into in future lessons."

**CT-READ: A Framework for Infusing CT into Elementary Classrooms**

The CT-READ framework includes five elements to support teachers in planning interdisciplinary lessons that position CT as a crucial tool for supporting students' content learning: (1) content and learning goal identification; (2) text selection; (3) read-alouds; (4) engagement in active experimentation; and (5) discussion (see Figure 2). Our hope is that the CT-READ framework and the lessons that we have learned while experimenting, tinkering, creating, and refining will support other teachers interested in utilizing CT to support content learning, particularly in relation to the development of scientific literacies.

[INSERT FIGURE 2 ABOUT HERE]

To illustrate how the framework functions in the design and enactment of lessons, we draw on the Decisions, Dragons, and Decomposition lesson, which aims to support students' understanding of key CT concepts and science content standards (see Table 2 for lesson overview). The read-aloud text for the lesson is *Dragons Love Tacos* (Rubin, 2012); in the story, the main character plans a taco party for dragons; when spicy salsa is accidentally served at the party, chaos ensues. While an initial draft of the lesson was developed by the research team, lesson materials and scaffolds have been co-created with partner teachers as they have adapted it for various grade levels. For example, as described below, two teachers, Ms. Callaway (1st grade) and Ms. Wright (5th grade), piloted the lesson in Spring 2020, with each choosing a different content learning focus based on their students' developmental levels and needs. In Fall

2021, the lesson was demonstrated during a Making CT monthly meeting, at which point, Ms. Vernon decided to use it in her classroom.

In the version of the lesson Ms. Vernon adapted for her fifth-grade classroom, which is featured throughout the following sections, students used decomposition to explore how tasks can be broken down into simple steps and algorithms to create a repeatable structure of steps to carry out a complex task. After discussing CT concepts and reading the anchor texts, students decomposed story events, planned a taco party by constructing an algorithm, and created Squishy Circuit party favors. The lesson addresses NGSS 4-PS-3, "making observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents" (NGSS Lead States, 2013).

[INSERT TABLE 2 ABOUT HERE]

### CT-READ Element 1: Content and CT Learning Goal Identification

*During the November 2021 Making CT meeting, after teachers read Dragons Love Tacos, learned about decomposition and algorithms, and made a variety of Squishy Circuit sculptures (including party hats, tacos, and spicy salsa), returning teachers Ms. Callaway and Ms. Wright, who had taught the lesson during the previous year, reflected on their experiences.*

*Ms. Callaway, a first-grade teacher, described how she connected the lesson to writing standards: "I focused really heavily on first what we need to do, then next, then last, and getting them to think about all the steps that we need to take to plan a party."*

*Ms. Wright, a fifth-grade teacher, shared that because her students were a "little older and a little more independent on the debugging themselves, we used it for writing, but we used it to sequence with whole paragraphs and words like 'however' and 'therefore.'"*

*After listening to her colleagues' reflections, Ms. Vernon decided to implement Decisions, Dragons, and Decomposition with her students. Rather than highlighting writing standards, as Ms. Callaway and Ms. Wright did, her goal was to have students decompose, or break down, complex scientific terms (e.g., conductor, insulator, resistance, closed circuit, open circuit, short circuit, and parallel circuit) and use the new vocabulary as they wrote algorithms for creating a Squishy Circuit. As Ms. Vernon reflected, "Decomposition goes hand in hand with algorithms. We take a look at our entire problem we are faced with, and use decomposition to break it down into smaller tasks that are easier to complete at once."*

The first step of creating a CT-infused lesson, and the first element of the CT-READ framework, is to identify both content area and CT learning goals. It's easy to get caught up in anticipating kids' excitement when you're thinking through all of the possibilities for engaging them in inquiry-based CT learning. However, in order to ensure that lessons stay focused on learning goals, it's essential to work backwards from standards and keep the end (student outcomes) in mind. Ms. Vernon, for example, reviewed upcoming standards and reflected on student needs to adapt an existing lesson that highlighted both CT (algorithms and decomposition) and content learning goals.

During Making CT, a key part of the monthly PD sessions was collaborative thinking time, when teachers considered upcoming units, reflected on links to CT concepts, and thought about opportunities for CT-infused content learning. For example, in the excerpt above, teachers from different grade levels shared their experiences with Decisions, Dragons, and

Decomposition and talked about how they used the lesson to center particular content learning goals in relation to writing. Teachers' experiences in teaching existing or adapted lessons provided crucial support for their colleagues in coming to think about how to approach or adapt lessons for their classrooms. As Ms. Callaway reflected, "It wasn't just the experts saying this is what you should do, which a lot of the times when you go to PD that's what you experience. It was more—you are guiding us to come up with decisions and sharing how you would do it…So many different brains come up with so many different thoughts."

**CT-READ Element 2: Text Selection**

*In a small-group breakout session in the November 2021 meeting, a group of three teachers and a project team member discuss Dragons Love Tacos.*

*"Decomposition–I am still wrapping my head around what it practically looks like to break down problems into smaller parts," Ms. Evans, a fourth-grade teacher, said.*

*Ms. Wright, a first-grade teacher, nods at the Squishy Circuit that she had just made. "When I taught this, the dragons, tacos, and party planning were all familiar for my kids. It really helped them to sequence the story."*

*"Yeah, I'm thinking that even though this book may be for younger kids, that it might let us really get to decomposition," Ms. Vernon said.*

After selecting content and CT learning goals, the next element of the CT-READ framework is to identify a text that can serve as the foundation for developing students' knowledge in a familiar context. A growing number of recently published books, including series by Josh Funk and Caroline Karanja, explicitly introduce CT concepts and vocabulary to children. These texts demonstrate real-world applications of CT and highlight key terms, such as abstraction and algorithms. However, we've also found myriad opportunities to introduce CT using a wide range of texts commonly found in many classroom and school libraries. The key is to select texts that have structures that connect to content standards and can facilitate discussions of specific CT concepts through plot events, character actions or traits, text structures, or themes. For example, identifying a text with a linear structure would be a good choice to introduce decomposition, while texts in which characters persevere through challenges can help students understand debugging. Based on our work with teachers and their feedback on texts that most successfully addressed CT concepts, we developed a set of guidelines for selecting texts for CT-infused read-alouds (see Table 3).

[INSERT TABLE 3 ABOUT HERE]

For Decisions, Dragons, and Decomposition, the idea for using *Dragons Love Tacos* as an anchor text initially came from a brainstorming session with teachers in early Spring 2021. The research team shared the criteria we had used to select texts that connected to CT concepts (outlined in Table 3), and the text *Dragons Love Taco*s was proposed. During the discussion, teachers talked about the accessible language, engaging visuals, and children's familiarity with the text and its sequel, *Dragons Love Tacos 2*, as well as glimmers of opportunity for introducing decomposition and algorithms.

The careful selection of an anchor text for CT-infused lessons provides many benefits: maximizing classroom time to bridge ELA and other content standards, introducing unfamiliar CT concepts using a familiar practice, and reinforcing CT across multiple lessons and learning experiences. In monthly sessions, reflections, and interviews, teachers described how highlighting literacy skills as part of their CT-infused instruction allowed them to "continue to hit the standards and tie everything together." The read-alouds also played a crucial role in building classroom cultures where students begin to see CT on a daily basis–as part of content learning, in their daily interactions with friends and family members, and as integral skills for future careers. When reflecting on her use of children's literature to teach CT, Ms. Wright shared that she had used several books in the past to connect CT to science concepts. As she said, "I love using the different stories, especially if you can tie a picture book to a particular standard, like the one about the tree that we did where we could tie it into science."

**CT-READ Element 3: Read-Alouds: Scaffolding and Creating Supports**

*Just prior to reading Dragons Love Tacos, Ms. Vernon asked her 5th grade students to "decompose" their daily routines: "What are the steps you take for brushing your teeth? Can you write down all of the steps in order so that you can repeat those steps each day?" After a class discussion, she began the read-aloud by priming students to focus on the CT elements: "As we read our book, I want you to think about how we just talked about sequencing and decomposition. This is about having a party, so in your mind, you can already be thinking about how to decompose the steps in having a party." As Ms. Vernon read, she paused to break down the text, purposefully using the terms "decomposition" and "algorithm." Following the read-aloud, the class wrote an algorithm for creating a taco and worked on anticipation guides for their Squishy Circuit party favor the next day.*

After identifying content and CT learning goals and selecting an anchor text, the next step in the CT-READ framework is to design explicit scaffolds for reading the text aloud to students. While a text might offer opportunities to introduce CT concepts, teachers must train their minds to recognize and take up these opportunities during the read-alouds. Ms. Vernon, for example, selected moments to pause when reading the text and purposefully used the terms "decomposition" and "algorithms" to familiarize students with the new terms. Determining the places to stop and speak is an important practice for teachers with all interactive read-alouds, but a necessary one when infusing new CT content into disciplinary ideas, skills, and practices.

In our co-planning work with Ms. Vernon and other teachers who implemented Decisions, Dragons, and Decomposition, we collaboratively identified targeted supports for the read-aloud at different grade levels, including pre-reading activities asking students to connect to their daily experiences (as evidenced in the excerpt above), questions to help students decompose story events, and task cards for early elementary students to help practice decomposition. Add in These scaffolds served to effectively differentiate the lesson based on grade-level standards and helped teachers target particular learning goals (in Ms. Vernon's case, decomposition, algorithms, and circuits).

In a broader effort to think through different read-aloud supports, during our collaborative workgroup sessions, we engaged in content analyses of several different children's books in small-group breakouts, in which teachers pointed to specific points in the texts where they saw explicit connections to CT concepts such as decomposition, debugging, abstraction, and algorithms. This also became a time when teachers revisited earlier elements of the CT Read Framework recognizing concepts in certain texts, gaining ideas for future lessons, and shifting their decisions based on collaboration with others. Teachers felt that the collaborative discussions helped them recognize opportunities to address CT concepts and dispositions before, during, and after the read-aloud. As Ms. Wright said,

> I have really enjoyed listening to the upper grades kind of break down how they would do things compared to how we would. So it's been very eye-opening to work together. We're all hitting problem-solving skills and using the same book, but we're all using it in such different ways. When I read a story, I don't always think about the same skills and processes and things that everybody else does.

**CT-READ Element 4: Engagement in Active Learning Through Making**

*On Friday morning in Ms. Vernon's classroom, the day after students had learned about decomposition and algorithms and read Dragons Love Tacos, multicolor LED lights flashed on and off in Squishy Circuit sculptures of tacos and dragons. All over the class, students used conductive play doh, LED lights, mechanical tools, and battery packs to craft their Squishy Circuits. Buzzers jolted the air at random intervals and a slight breeze brushed over the faces of a pair of students who tinkered with motors and propellers.*

*One student, Marcus, a 10-year old African American male, stared at two LED lights placed in his sculpture. While one light is working, the other is not. "How am I going to get this other light to work?" he wondered aloud.*

*As Ms. Vernon circulated among students, she overheard Marcus's question and suggested, "You may want to talk to Aaron."*

*Aaron saw the problem and the need to help Marcus debug his circuit. After making sure Marcus could see his circuit, he said, "You gotta…"*

*[Aaron moved the LED in his own circuit to show how the energy needs to flow between all elements to close the circuit.]*

*"Ohhhhh!!! I know how to do it now!" Marcus said.*

*Marcus eagerly went back to working on his Squishy Circuit, manipulating his model to improve his design and create a closed circuit.*

[INSERT FIGURE 3 ABOUT HERE]

As illustrated in the excerpt from Ms. Vernon's classroom above, the fourth element of the CT-READ framework, engagement in active learning, provides students with hands-on opportunities to engage in scientific literacy practices (see Figure 3). While some active learning activities in Making CT lessons involve coding tools such as Ozobots or block-based programs like Scratch, others focus on unplugged activities that address CT concepts (see Table 4 for sample lesson activities). The common thread throughout each active learning activity is students' engagement in tasks where they need to make, revise, rethink, and sometimes discard their products.

[INSERT TABLE 4 ABOUT HERE]

For Decisions, Dragons, and Decomposition, the primary active learning activity is the design of Squishy Circuit party favors and the creation of parallel circuits. Using Squishy Circuit kits, students are given the space and place to explore the cause and effect relationship between other circuit options and power sources with guided questioning. In order to support students in this process, research team members created a step-by-step guide for Squishy Circuit creation that was differentiated for students at different grade levels. In addition, we co-constructed a set of sample questions (e.g., "Describe your process. What did you do first? Then what happened?") for teachers to ask to help students debug to improve design and find solutions to any issues with their circuits. Ms. Vernon shared that the sample questions helped her students start to use the terms decomposition and algorithms and think through the process step–by-step to debug issues with their circuit. As she reflected, "I think making the light bulbs work was a really great "aha" moment that got the kids excited."

**CT-READ Element 5: Discussion and Synthesis of New CT Learning**

*As students continue to tinker with their circuits, Ms. Vernon gives her class a one-minute warning: "Let's come back together! Who wants to share their circuits?"*

*As students eagerly show off their creations, Ms. Vernon prompts them to think about how they decomposed the task. Students describe different steps in their processes, including coming up with their designs, examining circuit components, creating their party favors, and debugging circuit components. As a group, the class comes up with a step-by-step process for making a circuit.*

*"Can anyone share where they may have seen an algorithm before?" Ms. Vernon asks.*

*"In math?" a student asks.*

*"Yes! Okay, let's work on your exit tickets, where you'll write down your algorithms."*

In the final element of the CT-READ framework, discussion, students engage in metacognitive reflection about content learning outcomes, CT concepts, and CT dispositions, such as design thinking processes and collaboration. For each Making CT lesson, we worked with teachers to develop and test discussion guides that can be utilized to help students synthesize concepts in whole-class or small-group instruction. In addition, each lesson includes an exit ticket that allows students to reflect on content learning goals and their new knowledge both within and across disciplinary lines. For example, in the excerpt above, Ms. Vernon's students had opportunities to share their work, as well as reflect on where they had used the concept of algorithms in other areas. As she reflected, "I really think students grasped the concepts of decomposition and algorithms. They also were challenged with making the circuits work so they learned problem solving skills and how to embrace a challenge."

As we’ve worked with teachers, we’ve found that the discussion and reflection time is sometimes given short shrift due to lessons taking more time than expected or students’ desire to continue tinkering with new tools or ideas. However, we’ve also found that this time is absolutely critical for students to come to lasting understandings of new practices. A key focus for our collaborative work sessions has been to highlight the importance of the discussion and reflection elements and to create specific structures, including the exit tickets and discussion guides, to ensure that this essential piece is included in each lesson.

## Discussion and Conclusion

Even as more states and districts recognize the importance of CT in developing children’s scientific literacies, there has been a lack of concrete resources for teachers to learn to infuse these practices into their classrooms. Further, although a growing number of in-school and out-of-school programs offer computer science instruction as an enrichment activity or supplemental curriculum (Chen et al., 2017), these programs do not always allow for equitable access to computer science or CT for all students. If CT is taught as a stand-alone subject in school settings, it “runs the risk” of being reserved for students identified as high-achieving or gifted (Rich et al., 2020). Thus, in addition to promoting deeper understandings of disciplinary content, positioning CT as a key scientific literacy practice can promote more equitable access to computer science for all children.

The infusion of CT into elementary classrooms is an entirely new practice for many educators, and it’s essential to develop practical frameworks, tools, and structures to help teachers make CT a part of their regular instructional practice. We are grateful to have been able to learn alongside our teacher partners throughout the course of the Making CT project. As we’ve co-designed, co-taught, and reflected with teachers on lessons, we’ve gotten invaluable insight into the joy that teachers and students have found in playing, tinkering, and creating with CT and Making, as well as the very real barriers that they’ve faced. The CT-READ model, which was designed through collaborative work with teachers and analysis of their lesson planning processes, offers a practical framework to help teachers make CT infusion a regular part of their classroom practice.

Our work illustrates the potential of designing interdisciplinary, inquiry-based lessons to help students create, connect, and communicate using CT concepts, skills, and dispositions. Ideally, scaffolding CT through read-alouds and Making activities can create a bridge leading to classrooms where CT is modeled, taught, and used to help students understand disciplinary content and make sense of the world around them. We plan to continue working with our teachers to add to and enhance our library of freely available Making CT resources (website removed for blinding purposes). We hope that these resources can serve as a starting point to help other teachers interested in bringing CT into their classrooms, as well as illustrating how partnerships between teachers and researchers (Cochran-Smith & Lytle, 2015) can challenge existing research structures to work toward more collaborative pedagogies.

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