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# Teacher implementation profiles for integrating computational thinking into elementary mathematics and science instruction

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**Abstract**
Incorporating computational thinking (CT) ideas into core subjects, such as mathematics and science, is one way of bringing early computer science (CS) education into elementary school. Minimal research has explored how teachers can translate their knowledge of CT into practice to create opportunities for their students to engage in CT during their math and science lessons. Such information can support the creation of quality professional development experiences for teachers. We analyzed how eight elementary teachers created opportunities for their students to engage in four CT practices (abstraction, decomposition, debugging, and patterns) during unplugged mathematics and science activities. We identified three strategies used by these teachers to create CT opportunities for their students: framing, prompting, and inviting reflection. Further, we grouped teachers into four profiles of implementation according to how they used these three strategies. We call the four profiles (1) presenting CT as general problem-solving strategies, (2) using CT to structure lessons, (3) highlighting CT through prompting, and (4) using CT to guide teacher planning. We discuss the implications of these results for professional development and student experiences.

**Keywords** Computational thinking · Integration · Elementary school · STEM · Teacher education

## 1 Introduction

In recent years, there have been increasing calls across the globe to bring quality computer science (CS) instruction to all students in primary and secondary schools (Grover and Pea 2013; Yadav et al. 2016). This has led to efforts such as CSforAll in the United States,

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Computing at School in the UK, and several other efforts to introduce CS ideas to young learners. Many are in favor of exposing students to CS concepts and practices through *computational thinking* (CT), which is loosely defined as the mental tools, such as abstraction and decomposition, used within computer science to solve problems (Wing 2006).

Motivated, in part, by the need to fit computational thinking instruction into an already full school day, several recent efforts at the elementary school level have aimed to integrate computational thinking ideas into core subjects such as mathematics (e.g., Israel et al. 2015; Rich et al. 2017). While knowledge is beginning to emerge about how elementary teachers see CT as connected to their existing teaching practices (Yadav et al. 2018; Rich et al. 2019), there are few detailed descriptions of how CT is integrated into core subjects in elementary classrooms. In this paper, we present strategies and profiles detailing how eight elementary teachers created opportunities for their students to engage in CT during mathematics and science lessons.

## 2 Background

### 2.1 Computational thinking

As proliferation of technology continues to have profound impact and change the way we operate in the world, providing all students with access and opportunities to engage with computer science ideas is critical (Wing 2006). While preparation for jobs that increasingly require knowledge of computing is one benefit of including CS education in K-12, the benefits are broader (Israel et al. 2015). Exposure to the problem-solving processes used in computer science has the potential to prepare K-12 students to be engaged problem solvers both in their careers and in their everyday lives as citizens (Gretter and Yadav 2016). This is true even if they do not choose careers directly related to computer science.

In recent years, the CS education field has been exploring ways to communicate that CS is more than something only computer scientists do, and learning CS is more than strictly learning to program. The term *computational thinking* (CT) has gained popularity as a name for the practice-based, conceptually oriented aspects of computer science (Bocconi et al. 2016; Denning 2017). Specific definitions of computational thinking and the kinds of thinking processes it includes remain under debate, although certain processes appear across many definitions and descriptions. In a review article, Grover and Pea (2013) identified nine elements of CT including abstraction and pattern generalization, structured problem decomposition, and debugging and systematic error correction. To frame their proposed model for integrating CT into preservice teacher education, Yadav et al. (2017) highlighted four processes embedded within Wing's (2006) seminal description of CT: decomposition, algorithms, abstraction, and automation. Similarly, a European Union report aimed at guiding development of CT in compulsory education identified six core CT skills: abstraction, algorithmic thinking, automation, decomposition, debugging, and generalization (Bocconi et al. 2016).

This paper reports on one aspect of the CT4EDU project, a research-practitioner partnership between researchers and elementary teachers to co-develop and implement math and science lessons that integrate CT into teachers' existing teaching practices. In an effort to focus our work with teachers on understanding how they implement CT—and not on defining and redefining CT—we focused the project on four CT practices:

abstraction, decomposition, debugging, and patterns. We chose to emphasize decomposition and patterns because interviews with our participating teachers suggested they saw many connections between these practices and their mathematics and science teaching (Rich et al. 2019). We chose to emphasize debugging because, although teachers were not initially familiar with the term, a focus on finding and correcting mistakes appealed to them. Finally, we chose to focus on abstraction because although it was unfamiliar to our partner teachers, it has been identified as a particularly important CT practice by several CS education researchers (Armoni 2013; Hazzan 2008; Kramer 2007). Thus, we sought to find ways to make this practice useful and meaningful to elementary students and teachers. Table 1 provides our definitions of each of these four practices, in both teacher-facing and student-facing language. The student-facing language was developed by our partner teachers for use on classroom posters.

## 2.2 Integration as a path to CT instruction in elementary school

Some approaches to bringing computational thinking instruction into K-12 education focus on developing standalone CS/CT courses. For example, the Exploring Computer Science program (Goode et al. 2012) and the advanced placement Computer Science principles course (Astrachan et al. 2011) each emphasize problem solving and applications within the context of a computer science course. Another approach to bringing CT into K-12 education is to integrate CT ideas into instruction in other subjects. Mathematics and science may offer particularly fruitful opportunities for CT integration, given the inclusion of mathematics and computational thinking as a practice in the Next Generation Science Standards (NGSS 2013) and connections between CT and the Common Core's Standards for Mathematical Practice (Common Core State Standards Initiative 2010). Advocates of an integrated approach also argue that incorporating CT into a core subject helps to ensure the instruction reaches all students (Weintrop et al. 2016) and allows teachers to build on their existing content and pedagogical knowledge as they begin to introduce CT in their classrooms (Rich et al. 2019).

Studies focused specifically on CT in elementary school have suggested that integration of CT into core subjects may be the most successful pathway to providing CT to this age level (Duncan et al. 2017; Israel et al. 2015). After being introduced to CT concepts in professional development (PD), primary teachers in New Zealand created lessons that integrated CT into several other subjects (Duncan et al. 2017). The researchers credited

**Table 1** Focus CT practices and descriptions

| Practice | Teacher-Facing Description | Student-Facing Description |
|---|---|---|
| Abstraction | Reducing complexity by focusing on important elements of a problem or situation | Focusing on the information I need while ignoring unnecessary details |
| Decomposition | Breaking apart a complex problem or situation to make it more manageable | Breaking something down into smaller, more manageable parts |
| Debugging | Systematically finding and correcting problems and errors | Finding and fixing errors or mistakes |
| Patterns | Looking for similarities between new problems and problems that have already been solved | Looking for similarities and patterns between things |

this tendency to the particular situation of primary teachers, who teach multiple subjects to their students and therefore are in a position to facilitate connections across subjects. In a U.S.-based study of a school-wide initiative to incorporate CT into the curriculum, many of the classroom teachers chose to integrate CT into other subjects because the pace of the curriculum was too rapid to allow time for an entirely new subject (Israel et al. 2015). The researchers described integration as “key to successful implementation” of CT (Israel et al. 2015, p. 268). For these reasons, our efforts focused on supporting our partner teachers, who all taught at the elementary level, in integrating CT into their mathematics and science teaching. In an effort to stay close to teachers’ exisiting practices, we took an “unplugged” approach and worked with teachers to incorporate CT into math and science lessons that did not involve using computers.

### 2.3 Teacher knowledge and models of implementation

Teachers use multiple forms of knowledge as they plan and implement instruction, including content knowledge of the topic of instruction, pedagogical content knowledge about how to effectively teach that content, and curricular knowledge of available instructional resources and approaches (Shulman 1986). Decades of research has illustrated the complex ways in which teachers’ knowledge affects their instruction (Toom 2017). For example, teachers’ content knowledge is related to how they specify learning goals for their lessons (Hiebert et al. 2007), and knowledge of how people learn is necessary in order for teachers to make informed decisions about how to proceed when their instruction is not initially successful (Darling-Hammond 2006). As such, it is not surprising that much of the existing research on elementary school teachers integrating CT in their instruction focuses on the ways teachers thought about CT and related it to other subject matter. Duncan et al. (2017) described ways primary teachers connected CT to other curriculum topics and misconceptions the teachers had about CT and computer science as a field. Yadav et al. (2018) reported how elementary teachers’ understanding of CT became more elaborate and nuanced over the course of a year of PD focused on integrating CT in science inquiry. Hestness et al. (2018) found that teachers in a professional development workshop made connections between CT and their existing knowledge of students, curriculum, and their school contexts.

While this emerging body of research is important, it is incomplete. Certainly, knowledge of how teachers connect CT to other knowledge has implications for the design of effective professional development for elementary teachers looking to integrate CT into their teaching, as it supports the identification for learning goals for teachers as well as strategies for helping teachers meet those learning goals (Duncan et al. 2017; Yadav et al. 2018). However, effective professional development must not only have goals for teacher learning, but also specific goals for teaching practice (Loucks-Horsley et al. 2010). The development of teacher content knowledge is of little use if teachers do not know how to translate this new knowledge into practice (Toom 2017). One way to support teachers to translate knowledge into practice is by including examination of examples of teaching and learning of new content in professional development (Loucks-Horsley et al. 2010). In addition to providing models for how teachers might incorporate what they have learned into their teaching, studying examples of implementation can illustrate for teachers the impact the new content and teaching styles have on students, thereby increasing teacher motivation to try new practices (Guskey 2002).

Research examining not only what teachers learn about CT from professional development, but also how they translate that knowledge into classroom practices, will guide the creation of professional development experiences that support additional teachers in translating CT knowledge into practice. While such studies are scarce, a few are emerging. Israel et al. (2015) described how elementary teachers implemented integrated CT instruction, focusing on the amount of explicit instruction teachers provided and whether they utilized whole-class or center-based instruction. In a case study of one teacher incorporating CT into science inquiry, Krist et al. (2017) described how the teacher took ownership of particular thinking strategies, such as using a flow chart, that she identified as computational thinking. In this study, we aim to add to this existing work by documenting specific pedagogical strategies elementary teachers used to provide opportunities for their students to engage in CT during math and science lessons. Further, we describe the various ways the teachers coordinated these strategies by grouping teachers into profiles of CT implementation.

### 2.4 Theoretical framework and research question

To guide our examination of teacher implementation, we used Carroll's (1963, 1989) concept of *opportunities to learn.* In his model of school learning, Carroll defined a student's opportunity to learn a topic, practice, or idea as the amount of time that student was exposed to that idea in the classroom. While acknowledging many other factors, including the quality of instruction and the student's motivation, would also affect student learning, Carroll argued that if any learning is to occur, students have to be given time for such learning. Teachers play a critical role in providing time for learning.

Providing opportunities to learn is closely tied to finding ways to support teachers to translate their knowledge of CT—and how it connects to their curriculum—into practice. To support the ultimate goal of students becoming proficient computational thinkers, teachers must provide opportunities in the classroom for students to learn how to use CT. The following research question guided this study: How do elementary school teachers create opportunities for their students to engage in CT practices during mathematics and science lessons? For our particular context and area of interest, we operationalized *opportunities to learn* as instances of students being given opportunities to engage in tasks and thinking that reflected the ways their teacher described our four CT practices.

## 3 Methods

### 3.1 Participants

This study included eight elementary teachers from five schools in a large intermediate school district just outside an urban area in the Midwest United States. The district included a total of 168 elementary schools and served a dense suburban area with a total population of 1.2 million. As mentioned above, the teachers were part of a researcher-practitioner partnership that focused on integrating computational thinking within elementary classrooms. A summary of the teacher and school demographics is in Table 2. Their years of teaching experience and school demographics varied, but the schools were chosen, in part, based on high percentages of minority students, students from low-income families, or English-language learners as compared to the national distributions of students enrolled in public schools. In fall of 2015, 51% of students enrolled in K-12 public schools in the United States were non-White and 10% were identified as English-language learners. Overall, 15% of children under 18 were living in poverty (National Center for Education Statistics 2019). Table 2 shows that each school exceeded these overall percentages in at least one category.

## 3.2 Materials

To support various aspects of this study, we developed a number of resources, for both teacher and student use, related to our four focal CT practices: abstraction, decomposition, debugging, and patterns (see Table 1). We include descriptions of the materials here because the completed lesson planning tools were one source of data for this study, and some of the materials for classroom implementation are referenced in the classroom video analyzed for this study.

### 3.2.1 Materials for professional development and lesson planning

To assist teachers in making connections between each of the four CT practices and their own classroom practice, we developed two teacher-facing tools. First, the *CT Lesson Screener* was developed to help teachers identify elements of CT already present in the lesson. Second, the *CT Lesson Enhancer* was developed to help teachers plan and implement lessons in ways that would make existing CT ideas more explicit or embed new opportunities for CT. Teachers used these tools during professional development workshops (described further below). These tools are available on the project website at ct4edu.org/resources.

### 3.2.2 Materials for classroom implementation

In addition to the lessons co-developed during the professional development workshop (described further below), we provided teachers with three resources to support the introduction of CT into their classrooms: (1) a *CT teacher toolkit* that served as a pocket reference for how each CT practice related to elementary mathematics and science (Yadav

**Table 2** Participant teaching experience and school demographics

| Teacher Pseudonym | Grade Level | Years of Teaching Experience | School Pseudonym | % Non-White | % Free & Reduced Lunch | % English Language Learners |
|---|---|---|---|---|---|---|
| Allen | 4 | 20+ | Harwood | 66.3 | 58.6 | ** |
| Burgess | 5 | * | | | | |
| Connors | 5 | 20+ | | | | |
| Danson | 2 | 20+ | Whitfield | 52.7 | 76.0 | 3.9 |
| Ellis | 4 | 15 | | | | |
| Foster | 3 | 4 | Spring Hill | 22.7 | 50.2 | 18.7 |
| Gaines | 5 | 5 | Mapleview | 41.8 | 62.5 | ** |
| Hawthorne | 5 | 3 | Harrington | 61.5 | 48.8 | 15.4 |

*This teacher did not disclose how long he had been teaching.

**Percent ELL for these schools was not available.

et al. 2019); (2) a set of student-facing *CT classroom posters,* developed by one of the teacher participants, which provided a definition, example, and list of facilitating questions for each practice (available at ct4edu.org/resources); and (3) two classroom-ready activities designed to introduce students to the four CT practices in an informal, playful way.

## 3.3 Procedures

### 3.3.1 Professional development

Prior to implementing CT lessons in their classrooms, teachers participated in three professional development workshops. In Spring of 2018, they received a preliminary introduction to computational thinking and discussed the ways in which CT ideas might apply to their mathematics and science teaching. In early Summer of 2018, they were formally introduced to four computational thinking ideas on which the remainder of the project would focus: abstraction, decomposition, patterns, and debugging.

In late Summer of 2018, teachers came to the third workshop with examples of their existing mathematics or science lessons (often from a district-provided textbook or other resource) that they felt were good candidates for CT integration. Working in small groups that included 2–3 teachers, 1–2 members of the research team, and sometimes a member of the school district staff, study participants used the *CT Lesson Screener* and *CT Lesson Enhancer* tools to create lesson plans to be implemented in the first few months of school. They spent one day planning a mathematics lesson, one day planning a science lesson, and one day sharing with the group the lesson plans they had created.

### 3.3.2 Implementation

When the school year started, each teacher chose when and how to formally introduce the CT practices in their classroom. All eight teachers displayed the CT classroom posters in their classrooms. At least three of them used the playful classroom activities (described under Materials) to introduce students to the four practices. After introducing the CT practices to students, each teacher implemented at least one CT lesson during the first half of the 2018–2019 school year. Some of the lessons extended across two class periods. We used tablets mounted on rotating tripods to record video of each lesson implementation. Teachers wore microphones that were synced to the recording devices, so the tripod base rotated to allow the camera to follow the teachers as they moved around their classrooms. One author was present at each implementation. Observers took field notes both during and immediately after implementation. The number of minutes of each day of instruction ranged from 25 to 81, with a median lesson length of 54 min.

## 3.4 Data sources

The observation notes and classroom videos of the CT lessons teachers planned during professional development are the main data source for this study. However, we also drew upon the teachers' completed *CT Screener* and *Enhancer* tools (lesson plans) to aid us in defining and identifying how teachers created opportunities for CT in their classrooms. As described below, we used each teacher's descriptions of each of the CT practices, present in either the lesson plans or the classroom video, to guide the video coding.

### 3.5 Analysis

#### 3.5.1 Developing CT descriptions

In order to identify and describe the ways teachers translated their conceptions of CT into practice, we first needed to understand how each teacher thought about each practice. To accomplish this, we reviewed each participant's lesson plans and classroom video and documented each time the teacher provided an explicit description of the meaning of a CT practice. Each teacher described each of the four CT practices at least once, except two teachers (Foster and Gaines) did not describe decomposition. As an example, the list of descriptions from one teacher (Ellis) is provided in Table 3.

#### 3.5.2 Identifying CT opportunities in videos

Next, we used each teachers' list of descriptions as a coding scheme for his or her classroom video(s). The first author identified segments of the videos that exemplified teacher-provided opportunities for students in the classroom to engage in each practice. For example, using the description in the first row in Table 3, segments were identified in Ellis's classroom video where the teacher provided students with opportunities to simplify a problem to make it easier to work with, or when students described themselves as doing so. For each segment, the author also recorded whether the description used to identify the CT segment was articulated within the lesson video (within the segment or elsewhere) or only articulated in the lesson plans. Across 12 days of instruction, there were 124 video segments containing CT opportunities.

#### 3.5.3 Coding CT opportunities

After identifying the relevant video segments, hereafter called *CT opportunities*, we developed codes to describe *how* the teacher provided students with opportunities to engage in CT. First, we generated brief descriptions of individual opportunities (e.g., "Teacher asks a student to look for a mistake, and afterward asks class to name the CT practice just used") and recorded dimensions along which the opportunities differed (e.g., immediacy with which students could engage in the practice, whether teacher mention of the practice was before or after students used the practice). We then

**Table 3** One teacher's (Ellis) descriptions of the four CT practices

| CT Practice | Description | Data Source(s) |
|---|---|---|
| Abstraction | Simplifying a problem to make it easier to work with | Lesson plan |
| Abstraction | Ignoring details that don't matter to the problem | Classroom video |
| Decomposition | Breaking something down, such as breaking a number into place-value parts | Lesson plan; Classroom video |
| Patterns | Looking for similarities across situations or problems | Classroom video |
| Patterns | Looking for numbers that make addition easier *(Given as an example rather than a full description)* | Lesson plan |
| Debugging | Examining and discussing work to find and correct mistakes | Classroom video |

iteratively grouped the opportunities according to these dimensions until we had a set of techniques that were clearly described and mutually exclusive. We called these techniques *strategies* for providing CT opportunities. The three strategies are summarized in Table 4.

The first author tagged each CT opportunity with the name of the CT practice and whether the name of the CT term was explicitly mentioned during the opportunity. If the name of the CT practice was stated by a teacher or student, the opportunity was coded as an *explicit mention of CT,* and if the name of the CT practice was not said aloud, the opportunity was coded as an *implicit use of CT.* We also coded each opportunity with the strategy the teacher used to provide the opportunity. The rightmost columns of Table 4 provide examples of explicit and implicit opportunities for each strategy. The full coding scheme is in Table 5. Note there were a small number of video segments ($N = 12$) where none of the teacher strategies applied. These were cases where students independently engaged in a CT practice, without the teacher creating a specific opportunity, and were coded as *spontaneous by student.*

After the first author coded all the video segments, she trained the third author to code the videos using a written codebook using 12 (10%) of the coded video segments. After training, the third author coded an additional 31 segments (25%) independently. The segments used for training and for independent coding were randomly selected. The second coder was given timestamps for the CT opportunities, but independently coded them according to CT practice, Explicitness, and Strategy as a reliability check on the first author's coded descriptions of the opportunities. After checking the reliability of the first round of coding, the first author made minor adjustments to the codebook, and the two coders each made adjustments to their codes accordingly. After this adjustment, the Cohen's Kappa values were 0.81, 0.94, and 0.71 for the three sets of codes in Table 5, respectively. Given the moderate to strong agreement, we proceeded with the first author's coding.

#### 3.5.4 Developing teacher profiles

When coding was complete, we counted the number of times in each day of instruction the teacher used each strategy, sorting the opportunities according to whether or not the CT practice was named explicitly. We also developed brief narrative descriptions of how each teacher used each strategy in their classroom implementations. When describing the explicit versus implicit opportunities, we were attentive to whether the CT opportunity was based on a description of CT articulated elsewhere in the video. That is, we noted whether the description was made available to students during the lesson or based only on a description in the teacher's lesson plans that was never communicated to students. We felt this distinction was relevant, as it could impact whether the students were aware of their own opportunities to engage in CT.

Using these numerical and narrative descriptions, along with counts of how many of the CT practices were explicitly mentioned in each lesson, we looked for similarities and differences across lessons and across teachers. Based on these similarities and differences, we grouped teachers into four profiles of implementation and wrote descriptions of each profile. Note that although four of the teachers had two videos (either two lessons or two days of instruction on the same lesson), each with a different

**Table 4** Teacher strategies for creating CT opportunities

| Strategy | Description | Examples of Teacher Talk | |
|---|---|---|---|
| | | Explicit Mention of CT | Implicit Use of CT |
| Framing | Teacher describes an opportunity students will have to engage in the practice later in the activity. These descriptions frame the activity as requiring students to use the practice, and could prime students to begin thinking about how they might use the practice. | *Allen:* "Today you're going to look for **patterns** ... of what happens when things are going on with rounding, so we can come up with a strategy that's more efficient." | *Allen:* "We're going to generalize now. We're going to create a strategy that we will always be able to use." *(This is consistent with how Allen describes abstraction elsewhere in the video, but she does not name it as abstraction here.)* |
| Prompting | Teacher prompts students to consider engaging in a CT practice, with the presumption that students will begin using the practice immediately or shortly after the prompt. | *Burgess:* "Maybe if you guys finish, check your neighbor's. Check each others'. Do a little **debugging.**" | *Burgess:* "One of you want to go up and explain why you disagreed and fix what she had?" *(This is consistent with how Burgess describes debugging in the video, but he does not name it as debugging here.)* |
| Inviting reflection | Teacher highlights ways in which students have already engaged in a CT practice. These may include cases where the teacher describes how students used a practice and cases where the teacher asks students to describe how they used a practice. | *Gaines:* (after a student talks about setting aside denominators when adding fractions) "Which word was that? We talked about doing that [setting information aside] yesterday, too. We have a word for that." [Students answer **abstraction.**] | *Gaines:* "We found that the 1 in that mixed number we could kind of put away for now and look at the fraction pieces." *(This is consistent with how Gaines describes abstraction elsewhere in the video, but she does not name it as abstraction here.)* |

**Table 5** Full coding scheme for CT opportunities in lesson video

| Category | Codes |
|---|---|
| CT practice | Abstraction, Decomposition, Debugging, Patterns |
| Explicitness | Explicit mention of CT, Implicit use of CT |
| Strategy for providing opportunity | Framing, Prompting, Inviting reflection, Spontaneous by student |

quantitative and qualitative description, we did not see a great enough difference across a single teacher's videos to merit placing any of them in more than one profile.

As a preliminary examination of how the different teacher profiles lead to differences in student experiences, we also calculated the average number of CT opportunities per lesson for each profile. We also calculated how those opportunities were distributed across the four CT practices. Additionally, we noted the average number of instances of students spontaneously engaging in a CT practice in each profile.

## 4 Results

Table 6 shows the quantitative summary of the CT opportunities provided by each teacher in their CT lessons. The first column groups the teachers into the four profiles. The shaded cells highlight the key features of each profile. The narrative summary of each lesson is provided as an appendix Table 9.

Table 7 summarizes the four profiles in terms of how the teachers used the three strategies for providing CT opportunities for students. The sections that follow describe each profile in greater detail. We first give an overall summary, and then provide more detail about the way teachers in the profile used framing, prompting, and inviting reflection to create CT opportunities for their students.

### 4.1 Profile A: Presenting CT practices as general problem-solving strategies

The four teachers in Profile A (Ellis, Burgess, Danson, and Connors) utilized all three strategies for providing CT opportunities (i.e., framing, prompting, and inviting reflection) in their classrooms. Their use of the strategies reflected a conceptualization of the CT practices as general problem strategies that could be applied to a variety of problems. These teachers most often prompted students to use patterns or debugging in the moment; however, they framed their lessons with reference to all four practices and invited students to reflect on the use of all four practices. These teachers' lessons did not reflect significant focus on one particular practice. Rather, the teachers seemed to bring up the practices in opportunistic ways as they became relevant to the discussion. Additionally, almost all of these teachers' uses of the strategies involved explicit references to CT or implicit references that mirrored the meanings they made explicit to students elsewhere in the lesson. We refer to this profile as *presenting CT practices as general problem-solving strategies.*

**Table 6** Quantitative summary of CT opportunities provided by class period

| Profile | Teacher and Day or Lesson (Grade) | No. CT Practices Mentioned per Class Period | Framing | | Prompting | | Inviting Reflection | |
|---|---|---|---|---|---|---|---|---|
| | | | Exp. | Imp. | Exp. | Imp. | Exp. | Imp. |
| A: CT as Problem-Solving Strategies | Ellis (G4) | 4 | 1 | 0 | 2 | 2 | 7 | 0 |
| | Burgess (G5) | 4 | 4 | 0 | 2 | 6 | 3 | 4 |
| | Danson (G2) | 4 | 1 | 0 | 6 | 2 | 6 | 1 |
| | Connors (G5) | 4 | 2 | 0 | 5 | 0 | 6 | 1 |
| B: CT to Structure Lessons | Foster, Day 1 (G3) | 1 | 0 | 2 | 0 | 6 | 1 | 1 |
| | Foster, Day 2 (G3) | 1 | 2 | 0 | 0 | 3 | 0 | 0 |
| | Allen, Lesson 1 (G4) | 2 | 3 | 1 | 2 | 5 | 0 | 0 |
| | Allen, Lesson 2 (G4) | 3 | 3 | 0 | 1 | 0 | 1 | 0 |
| C: CT through Prompting | Hawthorne, Lesson 1 (G5) | 1 | 0 | 1 | 3 | 0 | 0 | 2 |
| | Hawthorne, Lesson 2 (G5) | 2 | 0 | 0 | 6 | 0 | 0 | 0 |
| D: CT for Teacher Planning | Gaines, Day 1 (G5) | 2 | 0 | 0 | 0 | 4 | 2 | 1 |
| | Gaines, Day 2 (G5) | 1 | 0 | 0 | 0 | 0 | 1 | 0 |

#### 4.1.1 Profile A framing

As shown in Table 6, all of the framing present in these teachers' lessons was explicit. The ways in which the teachers thought about the CT practices were usually present in the lesson plans, but they were also made clear to students during the lesson when the teacher made a framing statement—that is, a statement that primed the students to begin thinking about a particular CT practice.

The framing used by the teachers in Profile A took two forms. First, three of the four teachers began their lessons by reviewing the four CT practices with students, and then making a general statement about opportunities for students to use the practices during the lesson. For example, after asking volunteers to describe each of the four practices, Danson told her second graders, "We are going to use, actually in this lesson we're going to do, we're going to look at patterning for sure, abstraction for sure, possibly

**Table 7** Summary of teacher profiles for providing CT opportunities

| Profile | Framing | Prompting | Inviting Reflection |
|---|---|---|---|
| A: CT as Problem-Solving Strategies | Explicit framing statements for all four or one CT practice at a time. | Mix of explicit and implicit prompts. Implicit prompts mostly reflected earlier explicit mentions in video. | Mostly explicit invitations to reflect on all four CT practices, one at a time. |
| B: CT to Structure Lessons | Explicit framing of one or two CT practices. | Implicit prompts usually connected to the CT practices that were framed earlier or would be reflected upon later. | Occasional explicit invitations to reflect on one CT practice. |
| C: CT through Prompting | Occasional implicit framing. | Explicit prompting to use 1–2 CT practices. | Occasional implicit invitations for reflection. |
| D: CT for Teacher Planning | No framing. | Implicit prompting to use 1–2 CT practices as written about in lesson plans. | Occasional explicit invitations to reflect on how students used CT practices in earlier lessons. |

some debugging if we make a mistake, and breaking things down—decomposition." This statement, used by Danson, and similar statements by Burgess and Ellis, seemed to be intended to prime students' thinking about the practices before they began the lesson's main activities.

Second, some of the Profile A teachers' framing consisted of highlighting the way in which students might use one specific practice as they engaged in the lesson activities. For example, as Connors was introducing the day's sunrise/sunset science lesson to his fifth graders, he said, "What I want to do is … do some abstraction and think about, what can we look at? What can we look at if we want to talk about day and night and figure out what's happening?" Students did not offer answers at that moment in the lesson. Rather, Connors's question seemed to be intended to get students thinking in terms of abstraction as they generated scientific explanations about the sunrise and sunset. Ellis and Burgess also used similar statements or questions to frame their lessons. For example, Ellis said, "So what I want you to be looking for in your task today is, is there an abstraction? Is there anything that you need to ignore?"

#### 4.1.2 Profile A prompting

The teachers in Profile A prompted students to use a CT practice between four and nine times per lesson, and all prompts were focused on one CT practice at a time. All four teachers used at least one prompt that contained an explicit reference to a CT practice. For example, as his fifth-grade students worked on a problem, Burgess suggested they compare with their partners or groups and "do some debugging." Similarly, as her students helped her complete a chart organizing their answers to rounding problems, Danson prompted, "Let's use that word pattern again. What patterns do you notice?"

Three of the Profile A teachers also used some prompts that did not explicitly mention a CT practice. All but one of these implicit prompts reflected an understanding of the CT practice they expressed to students elsewhere in the video. For example, after explicitly prompting his students to debug early in the lesson, Burgess asked a student to "fix what [another student] had," which is consistent with the way he talked about debugging earlier in the lesson but not called out explicitly as debugging. Similarly, shortly after the explicit reference to patterns in the chart mentioned in the previous paragraph, Danson implicitly suggested students look for patterns again by asking, “What do you notice?” in reference to the more fully completed chart.

In one case, a teacher’s implicit prompt did not reflect a description from elsewhere in the video, but rather only reflected what was written in the teacher’s lesson plan. Specifically, one of Burgess’s prompts reflected decomposition as articulated in his lesson plan, where he wrote that students should, “*Decompose* your group’s number and write just your digit’s value on your board” (emphasis added). As he planned, he seemed to see breaking numbers into place value parts and thinking about one digit at a time as an example of decomposition. In his classroom video, he told a student, “You can look at each place value at a time. So you can look at the tenths to tell what’s happening.” He did not, however, explicitly note that doing so was an example of decomposition as he spoke to the student.

#### 4.1.3 Profile A inviting reflection

Each of the Profile A teachers invited students to reflect on how they had used CT practices seven times per lesson. As shown in Table 6, 22 out of the 28 invitations to reflect included explicit reference to a CT practice. While these invitations varied in form, most often teachers asked students to describe how they used a particular CT practice in an activity they just completed. At the end of her lesson, for example, Ellis asked her students to reflect on what they did by asking, “What about abstraction? Was there anything that needed to be abstracted?” All four teachers asked questions similar to this. Ellis and Connors also occasionally asked students to name which CT practice they had just used. For example, Connors asked a student “What were you doing there by looking at one smaller thing instead of the whole planet at once?” The student responded that she had used abstraction. With her second graders, Danson tended to describe what a students had done in terms of one of the practices, rather than asking the students to name the practice they had used. For example, as students modeled even and odd numbers with linking cubes, she said, “We’re using decomposition. We’re breaking down our numbers into smaller parts.”

While most of the invitations to reflect were explicit, there were six times when Profile A teachers used implicit invitations to reflect on use of a CT practice. Five of these implicit invitations to reflect mirrored ways of thinking about the practices that were made explicit to students elsewhere in the video. For example, toward the end of his lesson, Connors asked, “What did we see between the two models? Was there anything we were able to focus in on? Was there anything we might want to ignore?” This is consistent with how he described abstraction earlier in the lesson, but he did not use the term abstraction in the invitation to reflect. The explicit and implicit invitations to reflect on CT were spread across all four of the CT practices.

### 4.2 Profile B: Using CT to structure lessons

As shown in Table 6, the teachers in Profile B, Foster and Allen, tended to make explicit statements to frame the CT in their lessons, and/or explicitly ask students to reflect on their use of CT. They supplemented these strategies by implicitly prompting students to use CT during the lesson. The CT opportunities they offered were distributed across two or three of the CT practices in each lesson, but each teacher primarily focused on one particular practice. Their focus on one practice, combined with their tendency to rely on framing, suggested they planned and implemented their lessons with one practice in mind. We refer to this profile as *using CT to structure lessons.*

### 4.2.1 Profile B framing

Eight out of the 11 framing statements used by the Profile B teachers were explicit. Both Foster and Allen described to students what they were going to do in the lesson, connecting the activities to one particular CT practice. Foster, for example, asked students to identify which CT practice they would be using. Students in her classroom constructed cardboard rockets, called *hopper poppers,* that launched from their tables powered by rubber bands. Foster framed the activity of testing and modifying the hopper poppers as follows: "You're going to have a chance to test your hopper popper. The one you already made. And then you're going to have a chance to fix your hopper popper. OK, looking up at my CT wall, after we test our hopper popper and we get a chance to fix it, raise your hand if you see what CT skill we're going to be using." The CT wall refers to a section of the classroom wall showing the posters that highlighted the four CT practices (see Section 3.2). In response to her question, a student identified debugging as the relevant skill for the hopper popper testing. Similarly, Allen named the CT practice within her lesson framing. For example, she framed one of her lessons around patterns by saying, "Today you're going to look for patterns and you're going to generalize for us a strategy of what happens when things are going on with rounding, so we can come up with a strategy that's more efficient." Foster framed her lesson around debugging only, whereas Allen included framing statements about patterns and abstraction in one lesson, and abstraction and debugging in the other. The three implicit framing statements used by the Profile B teachers reflected meanings and examples reflected elsewhere in the videos.

### 4.2.2 Profile B prompting

In contrast to the explicit prompting used by teachers in Profile A, Table 6 shows the prompting used by teachers in Profile B was mostly implicit. Many of these implicit prompts were consistent with the way a CT practice had been framed earlier in the lesson. For example, after framing Day 2 of her lesson in terms of debugging (as highlighted in Section 4.2.1), Foster implicitly prompted two of her third graders to debug how they were using their hopper popper by asking, "Look at my video. Look at the way my hopper popper is. Do you see [what's different about yours]?" Similarly, after framing her lesson in terms of patterns (as highlighted in Section 4.2.1), Allen implicitly prompted her students to look for patterns by asking questions such as, "What do you notice about these numbers?" Interestingly, although Allen used a framing statement about abstraction in this lesson, she did not prompt students to use abstraction during the lesson.

During the first day of her lesson, Foster's implicit prompts did not correspond to an explicit framing statement. Rather, her implicit uses of prompting on this day seemed to serve two purposes. Some prompts seemed to be aimed at setting up a reflection opportunity at the end of a discussion. For example, after twice asking her students to identify similarities between two videos they had just viewed, she referred to her classroom CT posters and asked her students, “What did we just look for? Which of those CT skills did we just use?” A student identified patterns as the CT practice and described how they had used patterns. Some of Foster’s other implicit prompts were about debugging, which suggests her purpose was to foreshadow the more explicit debugging she had planned for the second day of the lesson.

Although most of the implicit prompting used by the Profile B teachers reflected meanings made explicit elsewhere in the lesson, there were a few examples of Foster implicitly prompting students to engage in a practice as described in her lesson plans, but never made explicit to students. For example, one activity in Foster’s lesson was for students to figure out how children could beat adults in a game of tug of war. In her lesson plans, Foster identified the following question as an example of asking students to engage in abstraction: “What information was most important to come up with a solution? (size, strength, number of students, etc.)” She asked a very similar question in her lesson video (“What was an important piece? How could we beat an adult at tug of war?”), but never explicitly mentioned abstraction during her lesson.

#### 4.2.3 Profile B inviting reflection

The teachers in Profile B occasionally provided CT opportunities for reflection. Foster set up one opportunity for reflection via implicit prompting about patterns, as described in Section 4.2.2 (“What did we just look for? Which of those CT skills did we just use?”). She also invited students to reflect on debugging, without naming it as debugging, on the first day of her lesson. During Allen’s second lesson, she had a student share his guess-and-check strategy for solving a problem, then described the strategy as a kind of debugging. She said, “Guessing and checking is a wonderful strategy. In fact, it’s also called debugging.”

### 4.3 Profile C: Highlighting CT through prompting

Like the teachers in Profile B, one fifth-grade teacher, Hawthorne, focused on a subset of CT practices rather than all four. Unlike the Profile B teachers, however, Hawthorne relied mostly on explicit prompting to provide CT opportunities to her students. In her first lesson (see Table 6), Hawthorne’s explicit prompting was supplemented with implicit framing and implicit opportunities to reflect. The implicit framing was connected to the explicit prompts later in the lesson. Her invitations to reflect on CT, however, were not connected to her prompting. Rather, they referred to other CT practices not explicitly mentioned in the lesson. In her second lesson, Hawthorne used only explicit prompting, with no framing or invitations to reflect. As such, there seems to be less intentional structuring of Hawthorne’s lessons around CT than by the teachers in Profile B. We call this profile *highlighting CT through prompting.*

#### 4.3.1 Profile C framing

Hawthorne made one implicit framing statement in her first lesson. She was leading a full-class discussion about a set of related problems for which the answers to earlier problems can often be helpful in solving later problems—known as a problem string. As she moved from the first to the second problem in the string, Hawthorne said, "Remember, how do these problem strings work? We use the first problem to do what?" When a student responded that the problems get harder and harder, she confirmed that the problems "build on each other." In her lesson plan, she had identified the relationships among problems in problem strings as an example of patterning in CT, as so we coded this as implicitly framing the lesson around patterns. She did not explicitly mention patterns in her framing statement, although she did make the connection to patterns explicit in her prompts later in the lesson.

#### 4.3.2 Profile C prompting

Hawthorne used several explicit prompts in both of her lessons. In her first lesson, for example, her explicit prompts related to the example of patterns discussed in her implicit framing. After students had completed the second problem in the problem string, she said, "Remember, these build off of each other. Start looking for the pattern as we go on to our next problem." In her second lesson, which was about ordered pairs and coordinate grids, Hawthorne used explicit prompts for debugging and patterns. For example, when a student forgot to write parentheses around an ordered pair, she said, "What are we missing, can we think about it for a second? Debug, look at it? What do you think we're missing?" Additionally, after students completed a chart showing the coordinates of vertices of shapes that were translated and rotated in the coordinate plane, Hawthorne had students turn and talk to a partner about patterns they noticed in the chart, then share their thoughts with the whole class.

#### 4.3.3 Profile C inviting reflection

As shown in Table 6, Hawthorne implicitly invited reflection twice in her first lesson. In the first case, she described what a student did in terms of the understanding of decomposition she wrote into her lesson plan. Specifically, after a student described a strategy for solving one of the problems in the problem string, she said, "I see how you're breaking it apart." In the other case, she encouraged a student to explain to the class how he corrected a mistake, which was consistent with how she described debugging in her lesson plan. However, in neither of these CT opportunities did Hawthorne or a student say the name of the CT practice.

### 4.4 Profile D: Using CT to guide teacher planning

One fifth-grade teacher, Gaines, most commonly created CT opportunities via implicit prompting for students to use one or two CT practices that were highlighted in her lesson plans. She made few explicit references to CT practices during classroom instruction. On occasion, she did provide explicit opportunities for students to reflect on how they used CT, but these invitations to reflect most often referenced the previous lessons, rather than ways students used CT within the same lesson. This lack of explicit references to CT within the lesson being taught suggests that CT played a larger role in planning than in classroom implementation. As such, we call this profile *using CT to guide teacher planning.*

### 4.4.1 Profile D framing

As shown in Table 6, Gaines did not use any explicit or implicit framing in her CT lesson.

### 4.4.2 Profile D prompting

Gaines's lesson focused on abstraction through discussion of various representations of fractions. In her lesson plan, she noted that students would be engaging in abstraction when they "Look at visual representations of mixed numbers, identifying the whole and the extra." On the first day of Gaines's lesson, she used prompts to provide two opportunities for her students to use abstraction as she described it in her lesson plans. In the classroom video of Day 1 of the lesson, Gaines asked students "What do you see?" and "How much do you see?" about two different representations of fractions: a visual model of 5/4 (two squares, each divided into fourths, with one entirely shaded and one with one fourth shaded), and a sum of unit fractions for 5/3 (1/3 + 1/3 + 1/3 + 1/3 + 1/3). During the discussion, she encouraged students who shared answers to explain where they saw the 1 or the whole. For example, when a student said the sum of unit fractions was equal to 1 2/3, Anderson asked, "Can you explain? Because I don't see a 1 anywhere up there, and I think some other friends are like, where is he getting 1 from or where is 2/3 from?" The student came to the board and drew a ring around 1/3 + 1/3 + 1/3, explaining that this was the same as 3/3, or 1. We coded this as an implicit prompt to use abstraction because it reflected the process of identifying the whole and the extra that Gaines had labeled as abstraction in her lesson plan. The word *abstraction,* however, was not used by the teacher or the students. Gaines's thinking about patterns, as written into the lesson plan, was similarly reflected in the classroom implementation without being named. (Gaines did not use any prompting on Day 2 of her lesson.)

### 4.4.3 Profile D inviting reflection

Four times Gaines offered opportunities for her students to reflect on CT they had already used, although in three out of the four cases, the previous use of CT had occurred on a different day. For example, in the first day of her lesson, Gaines said, "We had, yesterday, kind of debugged those fractions that were smaller than one." She also implicitly reminded students that on the previous day, they had set aside the whole-number parts of mixed numbers, focusing just on the fraction part. We coded this as an explicit reference to abstraction because Gaines explicitly referred to a similar strategy as abstraction later on in the lesson (see examples of inviting reflection in Table 4). Specifically, when a student referenced focusing on just the numerators and temporarily ignoring the denominators while adding fractions, Gaines explicitly invited students to reflect on this as a CT practice. She asked, "And which word was that? We talked about doing that yesterday, too. We have a word for that." The students then named the practice as abstraction.

### 4.5 Comparison of profiles

Table 8 compares the profiles in terms of the average number of CT opportunities teachers created for students in each day of instruction and how those opportunities were distributed across the four CT practices. The teachers in Profile A created the highest number of CT opportunities for their students, with those opportunities distributed across all four CT practices. The teachers in Profiles B and C created fewer opportunities, although the opportunities were focused on particular practices. The teacher in Profile D created the fewest opportunities (4), with those opportunities spread across two or three practices.

The available data did not allow us to analyze if or how students took up the CT opportunities created by the teachers. However, some of the videos showed a few instances of students engaging in the CT practices as described by the teachers elsewhere in the lesson, without a specific prompt or invitation to reflect from the teacher. The rightmost column of Table 8 shows the average number of times per lesson this occurred in each profile. It was an infrequent occurrence for all classrooms.

## 5 Discussion

This study contributes to a growing body of research exploring how elementary school teachers might translate their understanding of computational thinking practices in their mathematics and science teaching (e.g., Israel et al. 2015; Krist et al. 2017). Specifically, we shared ways elementary teachers created opportunities for students to engage in or reflect upon how they used CT practices during unplugged mathematics and science lessons. We identified three strategies teachers used to create CT opportunities for their students: framing tasks and lessons as requiring the use of CT practices, prompting students to engage in CT practices in the moment, and inviting students to reflect on the ways they had already used CT practices in lesson activities. Further, we grouped teachers into four profiles of CT implementation based on how many of the four CT practices they incorporated into each lesson, how

**Table 8** Summary of student CT opportunities by teacher profile

| Profile | Avg. No. of Opportunities per Day of Instruction | Distribution of Opportunities across CT Practices | Avg. No. of Times Students Spontaneously Used CT per Day of Instruction |
|---|---|---|---|
| A: CT as Problem- Solving Strategies | 15.25 | Distributed across all 4 | 1.25 |
| B: CT to Structure Lessons | 7.75 | Focused on 1 with some reference to 1–2 others | 1.25 |
| C: CT through Prompting | 6 | Focused on 1 with some reference to 1–2 others | 0 |
| D: CT for Teacher Planning | 4 | Distributed across 2–3 | 1 |

often they used each of the three strategies for creating CT opportunities, and when and how they spoke explicitly about CT practices during their lessons.

Teachers who used Profile A, *presenting CT as general problem-solving strategies*, utilized all three strategies (framing, prompting, and inviting reflection) to make their thinking about all four CT practices explicit to students in each lesson. Teachers who used Profile B, *using CT to structure lessons*, used framing and invitations to reflect to make explicit connections to CT, and supplemented this with implicit prompting for students to engage in the practices during the lesson. The teacher who used Profile C, *highlighting CT through prompting*, relied mostly on explicit prompts to create opportunities for students to use CT. The teacher who used Profile D, *using CT to guide teacher planning*, rarely made CT connections explicit to students, and instead used implicit prompting and reflection opportunities to bring her ideas about CT into the lesson. Although the Profile D teacher most often brought her ideas about CT into the lesson implicitly, there were examples across all three of the other profiles where teacher ideas about CT, as expressed in lesson plans, were embedded in the classroom implementation but not made explicit to students.

The strategies and profiles we identified in this study provide concrete examples of goals for teaching practice that could be incorporated in professional development alongside goals for teacher and student learning (Loucks-Horsley et al. 2010). In this section, we discuss how teachers might be best supported through professional development to use the three strategies to engage students in CT practices within their mathematics and science instruction. Further, we compare the profiles and discuss how their use may lead to differences in the ways students experience CT in the classroom. Our goal is not to advocate for one practice goal over another, but rather to highlight relevant differences to help teachers and teacher educators select goals and strategies that are a good fit for their context.

### 5.1 Implications for professional development: Supporting teachers in using the strategies

The three strategies used by teachers in this study to create CT opportunities differ in the learning opportunities they create for students. Specifically, *framing* and *prompting* create opportunities for students to use CT where otherwise they may not have done so. That is, they have the potential to increase the number of opportunities students have to use CT practices. In contrast, *inviting reflection* does not, in and of itself, create an opportunity to use CT. Rather, it creates an opportunity to recognize and name CT when it has already been used. Implementation of these different strategies will require different forms of teacher learning and support.

#### 5.1.1 Framing and prompting

Framing of a lesson, and prompting within a lesson, can largely be planned in advance. This was particularly evident with Profile B teachers who structured their lessons around a particular CT practice and foreshadowed how students would use the CT practice through framing statements early in the lesson. Additionally, it was clear that the Profile D teacher had planned prompts in advance, as her verbal statements in the lesson tended to mirror her plans closely. Thus, one way to support teachers in utilizing the framing and prompting strategies is to provide time in professional development workshops to create lesson plans that incorporate framing statements and prompts targeted to CT. Framing statements and questions (prompts) to ask students are common elements in existing frameworks for creating teacher lesson plans (e.g., Smith et al. 2008). We found the screener and planner tools we developed to be useful in focusing teachers' attention on the CT practices as they created lesson plans.

Teacher participants in other studies focused on integrating CT into other subjects in elementary school (Duncan et al. 2017; Israel et al. 2015) designed their own lessons without using a formalized template or framework, but the ways they organized their lessons suggest that framing and prompting could fit well into their planning. For example, several of the teachers in the Israel et al. (2015) study started their lessons with whole-class instruction—where framing statements could be used—and later circulated as students worked independently or in groups—where prompting could be used. Teachers in the Duncan et al. (2017) study sometimes taught a CT-focused lesson designed by the researchers, and then later connected the CT ideas to their subsequent math lessons. Framing and prompting could be offered to these teachers (or those following a similar model) as a way to explicitly connect CT ideas to mathematics or other subjects. Additionally, using the same kinds of framing statements and prompts within computationally rich activities later in the curriculum may also provide pathways for students to make connections between the exposure to CT practices they had in unplugged contexts to using the ideas in plugged contexts.

An additional way to support teachers in creating CT opportunities through framing and prompting is to support them in selecting or designing disciplinary tasks that are, in and of themselves, rich in opportunities for student thinking and problem solving. In our professional development workshops, we found that teachers had an easier time incorporating CT into rich, open-ended, inquiry tasks for mathematics and science that were intentionally designed to engage students in higher-level thinking. Teachers who were working with such tasks easily used framing and prompting to foreground aspects of the task and student thinking that aligned with their conceptions of the CT practices. Unfortunately, many elementary curricula for mathematics and science do not provide teachers with access to such tasks (Banilower et al. 2013; van Zanten and van den Heuvel-Panhuizen 2018). As such, creating CT opportunities through framing and prompting may first require teachers to design or redesign lessons—this was the case for some of our participating teachers. Although this made the co-design of lessons more difficult than we anticipated, it also revealed an unexpected, but potentially beneficial effect of teachers using CT practices as a lens for examining their existing math and science lessons: CT provided affordances for teachers to think deeply about their math and science instruction and how to allow more opportunities to engage their students in rich tasks. While our end goal is to provide pathways for teachers to create computationally rich activities for their students, the ways teachers used framing and prompting to redesign their lesson tasks was encouraging, particularly in Profiles B and D where the connections between lesson plans and implementation were clear. These teachers took up CT in ways that supported productive changes in their disciplinary teaching.

Providing more intentional support to teachers in designing and redesigning lessons may enhance these benefits, as well as support teachers and students in making connections between unplugged math and science lessons and computationally rich activities. Designing a lesson is a fundamentally different task than planning a lesson, as the former is focused on considering the purpose of the lesson and the latter is focused on the details of how a lesson will be carried out (Hathaway and Norton 2019). We intended for our *CT Screener* to focus teachers' attention on considering which CT practices to highlight—as part of the design and purpose of the lesson—and our *CT Planner* to focus teachers' attention on planning specific ways to bring CT into the lesson. The mixed experiences of our teachers in PD in ease with which they found ways to incorporate CT suggests that teachers needed greater support in the design phase.

Hathaway and Norton (2019) developed guidelines to support teachers' lesson designs. They recommend that finished lesson designs have multiple elements, including an explanation of the problem of practice the lesson is designed to solve, a clear list of constraints and requirements, a statement of the design problem, and potential learning activities. Engaging in a design process such as the one articulated by Hathaway and Norton may support teachers in creating meaningful CT opportunities for their students because it will provide an avenue for articulating the provision of CT opportunities as part of the goal of the lesson. Co-design has been successfully used in mathematics education as an element of professional development that supported teacher learning and teacher creation of task sequences that prompted particular kinds of thinking from students (Hansen et al. 2016). While this study provides a lens into how elementary teachers use unplugged CT practices in their math and science instruction, future research could examine how co-design during professional development could support teachers to create computationally rich, plugged CT opportunities for their students. There is limited work in this area, but one study by Finch et al. (2018) found that when co-designing a classroom unit with high-school teachers that used artistic sensor-data-driven representation of the garden, teachers' aesthetics and scientific aims motivated them to learn computing skills.

#### 5.1.2 Inviting reflection

Although teachers can purposefully design opportunities for students to reflect on the ways they have used CT, such as Foster's prompting in Profile B, our data suggests that teachers can also spontaneously notice and name students' use of CT practices. For example, Profile A teachers quite often either described what their students had just done in terms of a CT practice or asked their students to name which CT practice they had just used. Yet recognizing particular forms of student thinking is challenging task for teachers, especially in the complex context of classroom instruction (Heritage et al. 2009). Three of the four Profile A teachers, who created the most frequent opportunities for students to reflect on CT, had at least 15 years of teaching experience (and the fourth teacher did not disclose how long he had been teaching), suggesting that recognizing particular forms of student thinking is a skill developed with experience. Thus, professional development that provides practice for teachers to recognize when students are using CT practices could be helpful in supporting teachers to use the *inviting reflection* strategy in their teaching. One relevant professional development activity might be watching and discussing video of teaching, which has been shown to be effective for supporting teachers in recognizing students' mathematical thinking, and importantly, also in supporting teachers in translating the skills they gained into practice

(Sherin and van Es 2009). Future research could examine how observing and reflecting on CT-related teaching practice could be used to support teachers in creating opportunities for CT in their classrooms.

In our study, teachers created opportunities for reflection in a number of ways, including labeling what a particular student did with a CT practice and revoicing what a student did to highlight its connection to a CT practice. These modes of creating CT opportunities were consistent with the pedagogical strategy of assigning competence, or highlighting the intellectual value of a students' contribution or thinking (Boaler 2006). Assigning competence has been shown to contribute to the development of supportive relationships between elementary teachers and students, especially for African American and Latinx students (Battey et al. 2016). Given the goal of broadening participation in computing, helping teachers learn how to recognize and highlight how students use CT practices may not only provide teachers with new contexts for assigning competence, but also allow students from traditionally marginalized groups to see that they can engage in CT ideas. Future research in this area should examine whether and how integrating unplugged and plugged CT within elementary classrooms influences students' motivation and interest in computer science.

### 5.2 Comparing profiles: Focus and explicitness

The four profiles for CT implementation we described in this study differ along several dimensions. Two of these dimensions have the potential to impact both student experiences and teachers' professional development needs. These are focus and explicitness.

#### 5.2.1 Variation in focus across profiles

First, the profiles varied in the level of focus on particular CT practices. The teachers in Profile A created CT opportunities that were distributed across all four CT practices. By contrast, the teachers in Profiles B, C, and D limited the CT opportunities to two or three practices, with the teachers Profiles B and C seeming to focus on creating opportunities for one particular practice. The difference in focus seemed to relate to a difference in both the *quantity* and the *nature* of CT opportunities created for students. For example, the Profile A teachers, with a wider focus on multiple practices, created an average of about 15 CT opportunities per day of instruction—almost twice as many as any other profile. However, a narrower focus on one or two CT practices, as used by the teachers in Profiles B, and C, resulted in fewer opportunities.

Regarding the nature of the opportunities, the opportunities created by the teachers in Profile B and C were more likely to be related to each other. For example, the implicit prompts used by the Profile B teachers tended to connect to either their framing or their invitations to reflect. Although they were coded as separate CT opportunities in this study, these connected opportunities could also be conceived as examples of single, extended opportunities. By contrast, the teachers in Profiles A and D, who did not focus on a particular practice, did not make connections across strategies. Their framing and invitations to reflect were mostly disconnected from their prompting.

The classroom video data used in this study did not provide enough information for us to systematically evaluate the quality of the CT opportunities provided to students or how students responded to the opportunities, but we suspect that extended opportunities may have greater benefits than isolated, brief opportunities. Indeed, research in elementary science education suggests that extended opportunities to engage in scientific argumentation supported students in improving their abilities to construct and evaluate arguments (Ryu and Sandoval 2012). Thus, the variation in focus among the profiles highlights a potential tension between providing fewer, but extended and higher quality CT opportunities versus more, but briefer and less rich CT opportunities. Future research could explore the benefits and costs of each side of this tension for students' learning of CT ideas and explore how providing CT experiences in plugged versus unplugged environments helps to manage this tension. Additionally, future work could address the ways in which teachers are able to leverage brief versus extended CT opportunities provided in unplugged contexts to help students transition to plugged environments.

The focus on individual practices and creation of extended opportunities to use that practice, used by the teachers in Profiles B and C, may reflect a sense of comfort or familiarity with the focal CT practices by the teachers. Similar to the way that the case study by Krist et al. (2017) showed that the teacher took ownership of particular strategies, some of the teachers in our study seemed to take greater ownership of some CT practices than others. Future research could examine how teachers' senses of self-efficacy related to the CT practices affects the length and nature of the CT opportunities created for students.

The focused patterns of CT opportunities created by the teachers in Profiles B and C may also reflect more significant changes to the ways teachers would have implemented the lessons without attention to CT. The connectedness of the opportunities, especially in Profile B, suggests a fundamental rethinking of the lesson and its goals. On the other hand, the shorter, more frequent CT opportunities created by the teachers in Profile A suggest minimal changes to the lessons. Thus, Profile A may be easier for teachers to implement, especially when they teach in highly structured professional environments that, for example, place a high value on standardized assessments (Priestley et al. 2012; McGee et al. 2012). If the goal of integrating CT into elementary mathematics and science is to provide students early, informal exposure to CT-related vocabulary and concepts, the strategies used by the teachers in Profile A could be both easy to implement and effective for this purpose. If the goal of integrating CT is, on the other hand, to support students in using the CT practices independently, the strategies used by teachers in Profile B may be a better option. Future research examining the effect of each teacher profile on students knowledge of and attitudes about CT could help to guide decisions about what level of focus on particular CT practices is helpful and for what purposes. In particular, future research could unpack which profiles have the greatest advantages for supporting students in transitioning from unplugged to plugged contexts.

#### 5.2.2 Variation in explicitness across profiles

The second dimension of variation among the profiles worthy of discussion is the explicit mention versus implicit application of CT practices within lessons. The teachers in Patterns A and C used primarily strategies that included explicit mention of at least one CT practice. The teachers in Pattern B used explicit framing and invitations for reflection coupled with implicit prompting. The teacher in Pattern D used almost entirely implicit strategies. In their study of how elementary teachers implemented CT instruction, Israel et al. (2015) noted that teachers varied in the levels of explicit instruction they used in their CT lessons. In contrast to looking at explicit use of CT vocabulary, however, these researchers described a contrast between teachers who used didactic, full-class discussions and those who used open-ended, student-directed tasks. The teachers in the study acknowledged the importance of both types of instruction, but also all expressed worry that students would struggle with high-level CT without explicit instruction (Israel et al. 2015). The teachers in the current study expressed similar concerns about making high-level CT accessible to elementary students in their pre-project interviews (Rich et al. 2019). The varying levels of their explicit references to the CT practices may, therefore, reflect differing opinions about how to make the CT accessible. Some teachers seemed to believe that explicitly referencing the CT practices would support students in making sense of the practices, while others may have thought that emphasizing the vocabulary would add an unnecessary layer of complexity. Future research should examine the impact of explicit uses of CT terminology, in both unplugged and plugged contexts, on students' knowledge and skills.

## 6 Limitations

This study examined only one or two lessons implemented by each teacher in the study, leaving us unable to determine if teachers used these profiles of implementation consistently across the school year. We were also unable to analyze how students took up the CT opportunities created by their teachers, or how the inclusion of CT may have changed the nature of the mathematics and science taught or how students experienced it. As such, we intend this study only to provide examples of how elementary teachers take up CT as integrated with mathematics and science and their strategies for creating opportunities for their students to engage in CT. In future research, we plan to collect more student data to explore the differential impact of these implementation profiles and specific strategies for how students think about CT and apply it in the context of elementary mathematics and science. Longitudinal research could also examine the ways in which different opportunities to engage in CT in elementary mathematics and science impact students' attitudes about computer science, the rates at which they enroll in CS courses, and how they apply what they know about CT to CS courses.

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**Conflict of interest** The authors declare that they have no conflict of interest.

# Appendix 1

**Table 9** Narrative description of CT opportunities provided by each teacher

| Profile | Teacher | Framing | Prompting | Inviting Reflection |
|---|---|---|---|---|
| A: CT as Problem-Solving Strategies | Ellis | Framing of lesson suggested students think about all four CT practices | Several explicit prompts to use debugging | Explicit opportunities to reflect on all four CT practices |
| | Burgess | Explicit framing of opportunities to use decomposition, debugging, patterns. | Explicit prompts to use patterns and debugging. Implicit prompts to use all four CT practices. | Explicit reflection opportunity for patterns, implicit for other CT practices. |
| | Danson | Teacher reviewed terms at beginning of lesson, suggested students think about using practices. | Explicit prompts to use patterns and debugging | Explicit reflection opportunities for abstraction and decomposition. |
| | Connors | Explicit framing of opportunities to use abstraction, debugging, decomposition. | Explicit prompts to use all four CT practices. | Explicit reflection opportunity for all four CT practices. |
| B: CT to Structure Lessons | Foster Day 1 (G3) | Implicit framing of opportunity to use debugging. | Implicit prompts to use abstraction, debugging. | Explicit opportunity to reflect on patterns. |
| | Foster Day 2 (G3) | Explicit framing of opportunities to use debugging. | Implicit prompts to use abstraction, debugging, patterns. | No reflection opportunities. |
| | Allen, Lesson 1 (G4) | Explicit framing of patterns, abstraction. | Implicit prompts to use patterns. | No reflection opportunities. |
| | Allen, Lesson 2 (G4) | Explicit framing of abstraction, debugging. | Explicit prompt to use patterns. | Explicit opportunity to reflect on debugging. |
| C: CT through Prompting | Gaines, Day 1 (G5) | No framing. | Implicit prompts to use patterns, abstraction. | Explicit opportunity to reflect on abstraction, debugging. |
| | Gaines, Day 2 (G5) | No framing. | No prompting. | Explicit opportunity to reflect on debugging. |
| D: CT for Teacher Planning | Hawthorne, Lesson 1 (G5) | One implicit framing of opportunity to use patterns. | Explicit prompts to use patterns, debugging. | Two implicit opportunities to reflect on debugging, decomposition. |
| | Hawthorne, Lesson 2 (G5) | No framing. | Explicit prompts to use patterns, debugging. | No opportunities for reflection. |

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