Chapter 11
Connecting Computational Thinking and Science in a US Elementary Classroom

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Contents

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11.1 Introduction

The latest science education reform documents in the USA—*A Framework for K-12 Science Education* (*Framework*; NRC, 2012) and the *Next Generation of Science Standards* (NGSS; NGSS Lead States, 2013)—present a conception of science learning as consisting of three dimensions, where core ideas, practices, and overarching concepts for viewing the world work together and are developed synergistically. But this idea of three dimensions working in tandem has proven difficult for teachers to implement (Penuel, Harris, & DeBarger, 2015). Teachers are often seen as falling short of implementing the vision and theory expressed in the *Framework* (Haag & Megowan, 2015; Trygstad, Smith, Banilower, & Nelson, 2013).

A viable solution to this challenge is professional learning, new curriculum that aligns with the *Framework*, and a focus on assessment to drive change in practice and teacher beliefs (NRC, 2015). Key questions include "Are practices taught in the service of developing a core idea or do students apply a science idea in the service of developing scientific practices?" and "How do the three dimensions work together to support students in explaining phenomena?". We explore how project-based learning offers an approach that meets three-dimensional performance expectations through project-based learning where students make sense of a science phenomenon (Blumenfeld et al., 1991; Krajcik & Shin, 2014).

The *Framework* and NGSS standards shift the conception of science learning, yet there remains discussion in the field about the ideal way to combine and integrate the three dimensions of disciplinary core ideas (DCIs), science and engineering practices (SEPs), and crosscutting concepts (CCCs) to support three-dimensional learning for students (NRC, 2012). The disciplinary core ideas are the three or four generative and explanatory overarching ideas in the disciplines of life science, earth and space, physical science, and engineering. For example, *ESS2.C: The Roles of Water in Earth's Surface Processes* is a component idea of the larger DCI *Earth's Systems*. The crosscutting concepts (CCCs) describe "lenses" that can be applied across disciplines to ask questions of a natural event. For instance, the CCC *Patterns* can be applied to explain aspects of an ecological system to ask questions about plant and animal lifecycles, or the lens *Cause and Effect* can be used to ask about the loss of a species from a habitat. Finally, the scientific practices have overlapping features involved in scientific inquiry, including planning and carrying out investigations, developing models, or arguing from evidence.

The NGSS are performance standards that focus on doing science. Students develop a deeper sophistication in the science and engineering practices, disciplinary core ideas, and crosscutting concepts over time (NRC, 2012), and each dimension mutually reinforces the others. This approach is authentic, mirroring how scientists and engineers engage in practices (Engle & Conant, 2002; NRC, 2012).

In this chapter, we explore the integration of the dimensions through project-based learning. We address how the crosscutting concept *Patterns* and the disciplinary core idea *Particle Nature of Matter* can inform and be informed by the development of the science and engineering practice of *Computational Thinking*.

11.2 Disciplinary Core Ideas (DCIs), Science and Engineering Practices (SEPs), and Crosscutting Concepts (CCCs) Work Together

Unlike the work of practicing scientists who use DCIs, SEPs, and CCCs together to explain and predict phenomena and solve problems, "school science" has traditionally focused on explicating a science concept or completing a science unit or activity based on specific content (NRC, 2012). The emphasis in a traditional science classroom has been to acquire *science knowledge*. Sometimes an inquiry activity or investigation accompanies the acquisition of knowledge, but the activity or investigation is designed so that a student goes through steps to elicit the desired concept (Duran & Duran, 2004; Windschitl, Thompson, & Braaten, 2008). This prioritizes learning of science concepts with science practices subordinated to this end (Bartholomew, Osborne, & Ratcliffe, 2004; Shepardson, 2005).

There is a parallel trend in the post-NGSS literature to focus only on one *practice* at a time. Here, the science concept seems to be almost inconsequential (see Grooms, Enderle, & Sampson, 2015). In this literature, the pairing of science ideas with a practice occurs only after the practice is fully understood and conceptualized, suggesting a partially understood practice may offer little purchase for gaining science knowledge (Manz, 2012, 2015; Miller, Manz, Russ, Stroupe, & Berland, 2018). This approach positions practices as the primary focus.

Researchers have examined the usefulness of several SEPs, such as modeling (see Schwarz et al., 2009), explanation building (see McNeill & Krajcik, 2012), and argumentation (see Osborne, Erduran, & Simon, 2004), and how such practices with ideas work together to build knowledge (Pellegrino & Hilton, 2012). However, less is known about three important topics: (1) how to support elementary students in computational thinking—one of the eight scientific practices of NGSS; (2) how computational thinking can support elementary students in building scientific DCIs and CCCs over time; and (3) how deepening the practice of computational thinking enables students to work toward a more sophisticated capacity to use DCIs and CCCs.

This case study focuses on the question "What does the practice of computational thinking afford students in making sense of phenomena related to the core idea of the *Particle Nature of Matter*?". We add to the relatively nascent body of understanding around computational thinking, in terms of both how the practice develops and how its development informs thinking about phenomena using DCIs and CCCs.

Different practices offer specific advantages in terms of helping students make scientific sense of their world. For example, the practice of modeling amplifies the relationships between components in a scientific event and can force thinking about mechanisms (Schwarz et al., 2009). Argumentation is concerned with soliciting the most compelling evidence and reasoning to evaluate competing explanations (Osborne et al., 2004). Scientific investigation is ideal when an important understanding will become apparent with changing conditions, allowing students to question prior thinking (Miller, Lauffer, & Messina, 2014). Individual practices, in short, offer distinct perspectives and advantages or "affordances" for figuring out a phenomenon (Miller et al., 2014).

11.3 Using Project-Based Learning Toward Integrated Learning

Project-based learning (PBL) draws on several major theoretical ideas regarding learning, chiefly (1) active construction, (2) situated learning, (3) social interactions, and (4) cognitive tools (Bransford, Brown, & Cocking, 1999; NRC, 2007). PBL environments revolve around and focus on a driving question that children find meaningful, promoting a sense of wonderment and a "need to know" that propels learning. Because of PBL's focus on making sense of a meaningful question, its design principles reflect the vision of three-dimensional learning put forth in the *Framework* and the NGSS. Table 11.1 presents the various design principles of PBL.

We draw upon ongoing work in elementary science from the Multiple Literacies in Project-Based Learning (ML-PBL) project (Krajcik, Palincsar, & Miller, 2015). ML-PBL is a design-based project, using features of project-based learning (Blumenfeld et al., 1991; Krajcik & Shin, 2014), to create, develop, and test elementary curriculum to promote student learning of the big ideas of science and social emotional learning. Our approach integrates the development of teacher and student materials with long-term professional learning and assessments. ML-PBL is unique in that it integrates multiple literacies (i.e., reading, writing, math, and discourse) with the NGSS to support children in developing useable science knowledge.

This case study follows students as they explore phenomena of taste and smell to promote a "need to know" and engage in relevant contexts to build useable knowledge of the three dimensions. These phenomena elicit the SEP of *Computational*

Table 11.1 Design principles of project-based learning

1	Meet important three-dimensional learning goals based upon the NGSS performance expectations
2	Pursue solutions to *meaningful questions* anchored in the lives of learners
3	Explore questions by participating in authentic, situated science experiences using various science practices to "figure out" why phenomena occur
4	Engage in collaborative activities to make sense of phenomena through discourse
5	Use learning tools and other scaffolds to support students' participation in activities normally beyond their ability
6	Create artifacts—tangible products—that address the driving question and show students' emerging understandings

Thinking, the DCI of *Particle Nature of Matter*, and CCC of *Patterns*, to answer the driving question "How can I design a new taste?". The setting for this case study is a fifth grade classroom. The following sections provide a brief review of research on the practice of *Computational Thinking* and the core idea of the *Particle Nature of Matter*.

11.4 Conceptualizing Computational Thinking

The initial conception of computational thinking (Wing, 2006)—that it "involves solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" (p. 33)—galvanized education researchers in computer science and other domains to move beyond a focus on student programming to fostering the actual thinking computer scientists employ. Given our focus on developing innovative science curriculum materials, we gravitated toward conceptions of computational thinking that work well with a project-based learning approach and the vision of science education put forth in the *Framework* (NRC, 2012). The *Framework* specifies eight science and engineering practices students should use with DCIs and CCCs to figure out phenomena and solve problems. Computational thinking comprises part of a practice: *using mathematics and computational thinking* (NGSS Lead States, 2013). In the *Framework*, computational thinking refers to the capacity to use computational tools—including computers—and computational methods, such as constructing simulations, statistically analyzing data, applying quantitative relationships, and mathematically testing design solutions (NRC, 2012).

Wilkerson and Fenwick's (2017) discussion of computational thinking provides useful ideas from an NGSS perspective, noting a need to focus on examining the properties and relationships within systems and discerning patterns, often through engaging with—or creating—computer models of systems. We see this emphasis on understanding systems—like a given phenomenon—and the construction of computational models, an artifact, as working well with a PBL perspective that places final artifacts as the culmination of learning (Blumenfeld et al., 1991; Krajcik & Shin, 2014). Grover and Pea (2013) note how computational thinking has become more associated with a set of computational practices, rather than constrained to computer usage and programming (diSessa, 2000). Grover and Pea (2018) provide a set of concepts and practices that in their view encompass computational thinking (see Table 11.2). In our design of the fifth grade ML-PBL units, we make use of many of the concepts and practices of computational thinking delineated by Grover and Pea (2013, 2018).

Table 11.2 Computational thinking concepts and practices (Grover & Pea, 2018)

Concepts	Practices
Logic and Logical Thinking: the use of conditional logic to reach a conclusion about a problem (e.g., IF…THEN statements)	*Problem Decomposition*: the breaking down of a problem into more manageable sub-problems
Algorithms and Algorithmic Thinking: precise step-by-step processes for a solution	*Creating Computational Artifacts*: the development of a solution or model governed by computation (not necessarily digital)
Patterns and Pattern Recognition: identifying repetitions to help solve a problem	*Testing and Debugging*: the detection of flaws or inefficiencies in an approach
Abstraction and Generalization: the hiding of complex elements to create simpler representations	*Iterative Refinement*: the revision of an approach over time to better fit desired outcomes
Evaluation: the assessment of how well an approach meets criteria within specified constraints	*Collaboration and Creativity*: sharing labor and responsibilities and developing innovative and/or expressive solutions
Automation: implementing a solution on a machine	

11.5 Conceptualizing Learning of the Particle Nature of Matter

There is robust research on student thinking about the particle nature of matter. Andersson (1991) grouped students' developing understanding of conceptions of matter into four categories wherein each category is fundamental to deeper learning. Andersson's work in this area forms the basis of current thinking (Hadenfeldt, Liu, & Neumann, 2014; Merritt, Krajcik, & Shwartz, 2008). The categories are (1) particle nature of matter, (2) chemical reactions, (3) physical states and their changes, and (4) conservation of matter. The categories represent equally important aspects of matter and need to be developed as connected ideas in order for students to be able to explain related phenomenon (Liu & Lesniak, 2006).

In this case study, students are tasked to describe a mechanism for why the tastes in foods differ, based on the food being comprised of different particles, causing different perceptions of smell and taste. Students must recognize that foods are made of something that is experienced when the particles come into contact with a tongue mixed with saliva or by having invisible particles traveling to contact receptors in the nose. Through successfully explaining these related phenomena, students must be able to apply ideas from each of Andersson's categories. Finally, students recognize that there are some common compositions of particles in similar tasting foods.

The NGSS is organized so that one DCI is reiterated at each grade band—K-2, 3–5, middle school, and high school—but with increasing sophistication. The NGSS learning progression for science ideas introduces ideas and experiences at the earlier levels that are necessary to advance to the next level. For instance, for learners to develop the science idea of *PS1.B* at the middle school level, that *properties at the macroscale change as a result of rearrangement of atoms at the micro level*, they need to understand science ideas from *PS1.A* and *PS1.B* at the grade 3–5 and K-2 level. The idea that *substances have properties* is introduced at the K-2 level, but the learning progression does not show how students actually learn these ideas. We see PBL as an ideal method to engage students in "figuring out" phenomena using DCIs with CCCs and SEPs.

Learning progressions provide tools for teachers to support students in building future understandings. We build from Johnson's (1998) work on learning progressions discussed earlier. Johnson's (1998) third classification, that matter consists of particles, aligns with the ideas in the NGSS that learners should develop by the end of fifth grade. His fourth classification, that matter is composed of particles and the properties of matter depend on the interaction between particles, aligns with the level of understanding that students should develop by the end of middle school and which is necessary for more advanced DCIs at the high school level.

11.6 Description of the ML-PBL Unit: *How Can I Design a New Taste?*

Below is an overview of the five key lessons in this case study. The lessons come from the set of lessons (i.e., "learning set") for a PBL unit centered around the driving question "How can I design a new taste?". The learning set was designed to support students primarily in building their capacity to meet the physical science performance expectation *5-PS1-1 Develop a model to describe that matter is made of particles too small to be seen.* The unit, the second of four comprising a full year of curriculum, contains five learning sets with five lessons each. The five learning sets work together to answer the driving question and build across 5 weeks of instruction to address the following enduring understanding:

> Students will explain that foods may look similar but taste or smell different because they consist of specific and too-small-to-see particles. Foods such and salt and sugar are substances that have properties that can be described and used to identify them. Such substances behave differently when heated, cooled or mixed with other materials, which is also because of the particles that they are comprised of. In these conditions, the substances sometimes form a new substance with different properties, although the weight -- the total number of particles-- will not change. Some substances are made through nature-based processes, including the formation of the new substance, sugar, by plants.

In this case study, we are interested in how students build understanding of the focus performance expectation (PE) for Learning Set 1 through multiple practices, but particularly through computational thinking. These five lessons spanned 2 weeks.

11.7 Description of Learning Set 1

Lesson 1. The students engaged in the phenomenon that *foods have different tastes*. They developed related questions in small groups to share with the class. The class organized the questions and placed them on a "driving question board" for later use.

Lesson 2. The teacher presented the students with two foods, carob powder and cumin powder, with very similar visible properties but very different tastes. Students answered the question "Can you tell how a food tastes by the way it looks?" and then developed a model to explain the mechanism by which we taste foods. This lesson was designed to elicit initial ideas related to food being comprised of matter and particles which are too small to see.

Lesson 3. The students engaged in the practice of *conducting an investigation and collecting and analyzing data*. They predicted taste with their noses plugged in one trial and then without their noses plugged. The students developed a claim that smell and taste are related and smell adds to the ability to sense taste, although smell may be an "invisible" mechanism.

Lesson 4. Students returned to their models to revise, now needing to include smell and "invisible" particles. They presented their models to their peers.

Lesson 5. In the final lesson, students are guided in the practice of computational thinking through working on decomposing the phenomenon, recognizing and describing patterns, and engaging in iteration. They classify the taste of sweetness into three categories, categorize foods into them, and try to figure out how different foods can belong in the same category of sweetness.

11.8 Data Collection and Analysis

This case study took place within an elementary school in a lower middle-class neighborhood on the outskirts of a large urban area in the upper Midwest of the USA. The school has a student population in which 46% of students are classified as economically disadvantaged, 20.1% are English language learners, 42% are White, and the majority of the students of color are Latino (21.3%) and Black/African-American (17.9%). The remaining students are Asian and mixed race. Across grades K-5, 39% of students are considered "proficient or above" in English language arts according to the state reading proficiency assessment.

One fifth grade classroom with 25 students (with attrition of one student) served as the focus classroom for this study. The classroom typically was divided into collaborative groups with four students within each group. The classroom teacher, Ann (pseudonym), was in her first year of teaching the fifth grade ML-PBL science curriculum. This was also her first year teaching fifth grade; however, she had 15 years of teaching experience, primarily in fourth grade.

Data collection consisted of video recording student and teacher activity for the five lessons. The video camera and microphone captured the activity of a focus group as well as the teacher's words and instruction. The artifacts developed by the focus group during each lesson—questions, model, list of data, and computational graph—were also photographed. Student and teacher discourse and visible actions were transcribed verbatim in field notes.

This case study used an ethnographic approach to follow one group of four students within the classroom. The focus group was selected immediately after the first lesson in the unit, *How can I design a new taste?* The first lesson is designed to immerse students in an anchoring phenomenon: *foods taste different*. Our team collected questions developed by each group, aiming to find one group to follow based on their initial level of understanding. Our team used purposeful sampling based on the questions generated in this first lesson (Coyne, 1997), as questions that students ask can provide information about what students understand and care about in science (Chin & Brown, 2002).

We gave each of the six groups an average score for the three to five questions they asked. Group 5 had the fourth highest score of the six groups, and their average progression number fell in the middle between the highest scoring group and the lowest scoring group. For this reason, we selected Group 5 as our focus group. Group 5 had four students: one boy (White) and three girls (White, African-American, and Latina). All four students—Shay, Valencia, Ava, and Jacob—showed an interest in science, had consistent attendance and work completion, but, on average, tended to speak less often in class.

In analyzing the data, our approach involved both deductive and inductive coding of transcribed excerpts. We developed potential coding bins prior to analyzing the data and coded the data according to these bins, followed by a second round of analysis where we allowed for patterns to emerge from the data to serve as additional coding bins. Deductive coding bins fell along aspects of computational thinking put forth by Grover and Pea (2018), aspects of a progression for understanding the particle nature of matter put forth by Johnson (1998), as well as general bins for other aspects of DCIs, use of SEPs, or CCCs from the NGSS. Coding bins that emerged from the data included a focus on identifying productive learning moments and noting where students built on previous ideas.

11.9 Results

Below is an overview of what occurred during each lesson, interspersed with analysis relevant to our research question: *What does the practice of computational thinking afford students making sense of phenomena related to the core idea of the particle nature of matter?*

11.9.1 Lesson One: Using the Practice of Scientific Questioning While Engaging with a Phenomenon to get at the Particle Nature of Matter

The first lesson of five in the learning set introduced the larger learning set driving question, *What makes food taste the way it does*?, as well as the lesson driving question, *How can we best describe tastes?* The lesson involved engaging students in the phenomenon of different tastes. Each group sampled different foods and described their taste, focusing on differences in the properties of foods (i.e., color, shape, texture, and rigidity) and whether the properties are related or unrelated to the tastes. The foods included dried apricot, lemon slices, arugula, raisins, celery, tomato paste, fresh hot peppers, olives, and garbanzo beans.

After being introduced to the lesson Driving Questions, each small group sampled the foods and described the tastes. Then they discussed how the tastes were different or similar in a small group for share-out. The students then wrote questions on sentence strips.

Group 5, Shay, Jacob, Valencia, and Ava, tried all the foods and were highly motivated to ask questions. Group 5 engaged in *collaboration* (a key element of PBL) to develop the following questions:

Is a bean mostly made up of water?
Can some foods make your saliva poisonous?
Can we taste things that aren't food?
Why do we taste things?
People have different taste buds. Are we tasting what the food actually tastes like?
Is there sugar in dried fruit?
Are the nose and the mouth connected?

What purchase does the practice of asking questions provide for understanding taste in terms of the particle nature of matter? The practice of asking exploratory questions brings to the forefront various experiential resources that students have from their own lived experiences for making sense of a phenomenon. Group 5's questions include some useful ideas about the mechanism of taste (e.g., the notion that beans may be made of mostly water surfaces; ideas that there are different substances with different properties) and show they are beginning to think about how taste may be related to chemical change (e.g., that an interaction with food can make saliva change its properties). The students in this group are already considering what the foods they eat might have in them, but appear to be thinking of taste as having to do with something extra that is in the matter (sugar, water) rather than matter consisting of particles. Some of the questions show that students may be viewing foods as being comprised of smaller units (e.g., *Is there sugar in dried fruit?; Can some foods make your saliva poisonous?; Is a bean mostly made up of water?*) but note these units are smaller than a given unit of sugar, water, or poison.

11.9.2 Lesson Two: Using the Practice of Conducting an Investigation for Explaining and Predicting Phenomenon to Get at the Particle Nature of Matter

Ann wrote the new lesson driving question on the chart paper: *Can you tell how a food will taste by the way it looks?* The students carefully observed two brown-colored powders which were almost identical in appearance on two plates that Ann put in the middle of the circle on the carpet. One powder was cumin, and the other was carob powder, but the students did not know that. The teacher had the students call out "visible" properties of the foods, and she rapidly recorded what they said. Ann explained that the powders were not the same and asked the class "Can you make a guess about what the powders are and how they will taste based on these visible properties?". Most of the students guessed that one of the powders was cinnamon and will taste "cinnamon-y" and the other was chocolate and will taste "chocolatey."

After making predictions about which powder is which, the students taste a tiny sample of each. The students were surprised that two substances that looked so much alike tasted different, one sweet and earthy, while the other was bitter. Shay seizes on the idea that taste buds are responsible for this.

> Shay: (Explanation) Think about raisins. Ava loved them and now she hates them. I used *to love strawberries, I loved them. Now, yech. My taste buds changed*."

Initially Group 5 follows Shay's thinking and is mostly interested in how the taste buds are picking up tastes that get translated in the brain. They describe different interactions with taste buds. Shay recorded the groups' ideas in her notebook page, drawing the taste buds and the brain. She served as the scribe throughout most of their time working together. Shay wrote:

> Your taste buds change over the years. A lot of them die and a lot of them regrow and have you taste diff things.

Ann comes by the group. She goes over what the students have written so far, reading out loud, "The model shows that it is the brain picking up different messages from taste buds that causes the different tastes." She asks them, "Is it that the foods are basically the same stuff?". In posing this question, Ann pressed the group to show why the messages the brain receives might be so different between the two foods, moving them toward considering unseen characteristics. This led to an exchange in the group, where they *collaborate* on building their ideas:

> Jacob: I had for lunch chicken taco salad. There's meat in there and some lettuce. So does meat taste different from lettuce?
> Shay: Yes!
> Valencia: Yes!
> Ava: Yes!
> Jacob: Why? What's happening?
> Ava: Meat comes from animals and the leaves come from trees and God and they wash them. They are grown differently, and they also grow differently.

Shay wants to go back to taste buds, and the group engages in the question of food being a homologous substance versus a substance that contains particles of matter (level 2 in Johnson's (1998) progression).

Shay: Skittles let's do skittles … grapes and lemon. So, if you want to your mouth would detect what kind of food it is, so it gives you that kind of taste in your mouth.
Valencia : Grape skittles tastes nice, but it doesn't taste like a grape! You taste the flavor. If there wasn't any flavor then your mouth would be Yeach.
Jacob: Flavor is something that you taste that you might like or not like.
Ava: Minerals is the flavor. (The group agrees) They have flavor, tomato, chicken teriyaki, raisins."

Ann leans over and asks the group, "So what's happening here? There's one food and it tastes like something and then the other food and it tastes different?" "How can you show that they taste different, and why they taste different in your model?" Ann watches the group as they consider her words, and she says, "Keep thinking, you are doing great here!"

Ava asks the group to think about how the two substances came to be, using the word minerals again to explain taste.

Ava: You know how the food grows makes it taste. Like … if the soil has minerals in it, or if there are pesticides, then it gets in the food and makes the taste. (Shay looks to Jacob and then Valencia)
Valencia: This one, (points to the carob powder) tastes like it has minerals!

Shay has the pencil and records minerals in the page by placing dots and squiggly lines next to the tongue. In doing so, Group 5 demonstrates level 2 in Johnson's (1998) progression that matter contains particles: *The taste buds react to minerals and send a message to the brain then something happens in the brain.*

What purchase does modeling provide for understanding taste in terms of the particle nature of matter? The practice of modeling pushed the students' sensemaking to include invisible mechanisms. The students used simple aspects of computational thinking to debate the idea that foods have something in them, or added to them, that may be different across various foods (e.g., *If there wasn't any flavor then your mouth would be Yeach*). Specifically, students engaged in *decomposing* the phenomena of taste, developing a beginning understanding that smaller units with distinct properties contribute to the sensation of a given taste. However, they also hold the contradictory idea that *something responsible for taste* is an added but perhaps not essential component of the food. The students also have not ruled out the idea that taste buds and the brain cause the sensation of different tastes. While the modeling practice was useful for mechanistic reasoning, in this case it did not surface the contradiction. However, modeling promoted more discussion by forcing the students to concretely break down and represent abstract ideas. The students needed to make clear the interaction between components that result in taste.

11.9.3 Lessons Three and Four: Using the Practice of Investigation and Revising Models for Explaining and Predicting Phenomenon to Get at the Particle Nature of Matter

Instead of using the driving question in the materials, *How do we smell different tastes?*, Ann introduced this investigation based on one of the student questions asked in lesson one, *Can we taste with our nose plugged?*, which the class liked. They predicted smell would influence their ability to differentiate taste. Ann distributed skittles and had the students use blindfolds to conduct taste trials with their noses plugged and unplugged. Group 5 tried to explain why they were more accurate when their noses were unplugged.

Shay: Well I was thinking I have this theory. There is the taste that goes to the roof of your mouth. And when you taste something … (she trailed off) Well I don't know what I am talking about … Something about … It's like connected …
Ava: Your nose and your mouth. It's connected. In your mouth there is a passageway up to your mouth.
Shay: Then there is another passageway up to your brain!
Ava: Yeah. It goes up to your nose and there is like holes and so yeah.
Valencia: That is when you smell.
Shay: Yeah goes up to your brain.

Jacob pushes the students toward the invisible mechanism of smell, which prompts Shay to go back to taste buds:

Jacob: It goes up the aroma maybe. The things in your nose like if you have your nose plugged you can taste it like the back of your nose.
Ava: By it we mean food, it is food.
Jacob: Aroma. Some foods taste different than others right?
Shay: Cause there's taste buds on your tongue and on the roof of your mouth. (She pauses) And in the roof of your nose.
Valencia: The roof of your nose? (Laughs. All of the students laugh)

Ann comes by and asks the students how smell is working to help the taste. Ava responds, "The aroma maybe?". The students in Group 5 agreed that aroma is the same thing as food. The group added a nose and the same symbol for taste (the squiggly lines with dots for minerals) reaching toward the nose to their model.

What purchase does data analysis of an investigation provide for understanding taste in terms of the particle nature of matter? For Group 5, the investigation and data analysis made apparent that smell is a phenomenon that needs to be included in an explanation of different tastes. Yet, the intention of the lesson—to push students toward the need to explain "invisible" matter—did not occur. Using Johnson's progression between categories 2 and 3, the students are still in the gray area between *matter contains particles* and *matter is composed of particles*. They also seem to continue to hold onto the idea that particles could be comprised of a homogeneous substance (see Fig. 11.1).

(1) matter as a homogeneous substance	(2) matter contains particles, Particles are homogeneous substances	(3) matter is composed of particles	(4) matter is composed of particles and the properties of matter depend on the interaction between particles

Fig. 11.1 Students progression toward understanding particle nature of matter. Darker areas indicate more understanding achieved

11.9.4 Lesson Five: Using the Practice of Computational Thinking for Explaining and Predicting Phenomenon to Get at Particle Nature of Matter

Ann began class by going over with the class some of the questions they are still working on. She told the class:

> We have really been thinking a lot about taste and how we are tasting and smelling foods. But we need to think about patterns in tastes and foods. How is that foods have some tastes that are similar? We need to figure out patterns and describe what is happening when we encounter a pattern. That is something that scientists do.

Following the actions outlined in the curriculum, Ann had the students come up with a definition of *pattern* to refine later. The students came up with the following definition:

> Pattern: A pattern is the same sequence that repeats indefinitely. If something is in a pattern, you can use the pattern to predict what might happen. A pattern might not go on forever, but it could.

Ann told the students that they would refine the definition later on in the unit. She presented the task for the lesson while distributing plates of goji berries, dried apricot, tomato, orange, apple, and raisins:

> I am putting the foods out here and you have to figure out three categories to describe sweetness. I don't want you to describe the food. I want you to make three different categories for the experience of the taste of sweetness.

Ann sketched lines for three distinct categories on the whiteboard and continues:

> Like intensity, maybe, really strong sweet taste. Or, what sweetness also has with it, like another taste that accompanies the taste in different foods. For example, does sweetness come with sour in one food, and not in another. You have to describe the sweetness in three different ways, and then place the foods in the three categories. Can you do it? Do you need more examples?

The students in Group 5 sampled the food and quickly refined or engaged in *iterating* (a computational thinking practice) how to break up the way they tasted sweetness into three categories: (1) *sweet now*, (2) *sweet later*, and (3) *sweet the*

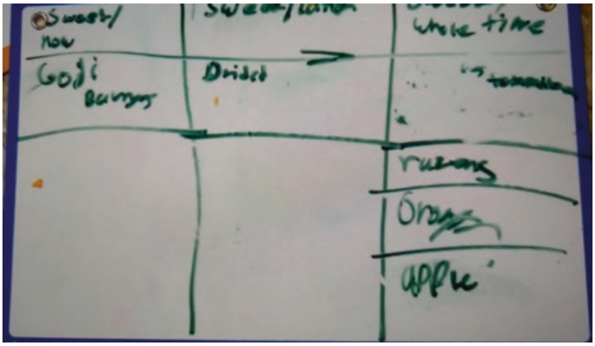

Fig. 11.2 Patterns of taste described by Group 5

whole time. The categories were based on trying the goji berries, which started out sweet and then tasted "bad." After figuring out the categories—essentially *decomposing* (a computational thinking practice) the phenomenon problem into smaller elements based on *patterns* (a computational thinking concept)—the group was able to categorize the different foods into the three categories, essentially recognizing *patterns* in the similarities and differences among the foods.

As seen in Fig. 11.2, the three patterns the students found across the foods are labeled: *sweet now*; *sweet later*; and *sweet the whole time*. In revising or *iterating* how to sort tastes in these categories, students re-engaged with the notion of matter being composed of particles. Ann asked each student group to denote one of their groups as the most courageous taster. She told the kids that they were going to taste a mystery food, and the taster would write one of the categories in their table. Then based on the table, the others would try to figure out how that taste could be described.

The students in Group 5 selected Ava to be the taster, who tasted a date. Her group studied her face while she tasted the date. Ava made the most of the moment, swishing the food around in her mouth like a sommelier. After the teacher's cue, Ava wrote "Dates" down in the first category and "Sweet now." Ann asked each group to see if they could try to identify what the mystery taste had been. The students discuss how to identify the mystery taste below:

Shay: So what I am thinking that you are tasting it. You first took a bite and it was like … she likes it. Before it was sweet and then it turned nasty.

Valencia: I know! Because you didn't put it in sweet the whole time!

Jacob: When I saw her facial expression it was kind of disgusting I think it was sweet when she first took the first bite and I saw her like … she did this (He makes a sweet face) that like she liked it. And then she took another bite and ah um (He changed his face to indicate that it stopped being sweet. The students all looked to Ava for assent. She gave them a thumbs up.)

Ann asked the groups to consider their charts:

Is there something the same about how you taste the things on one side of your chart compared to the other categories? How you tasted the sweetness in different categories? I want you to discuss with your groups and be ready to share. Is how you are tasting one group actually different from how you are tasting the other food in the other? What is the same in some foods that is different or the same in the other foods?

This line of questioning worked to spark discussion in Group 5. Jacob started with the idea of the taster physically moving the food to a particular taste bud purposefully, because they expect a certain taste, but Ava disagrees with Jacob:

Jacob: Um. It was like some time there was a lot of things that were sweet the whole time because sometimes you know where the taste is gonna go. When you don't know where it's gonna go you taste it and see what it tastes like.
Ava: How are these different from tasting those? He (Jacob) said that but there are so many things that weren't sweet the whole time. Not the whole thing, maybe part of the food is not sweet
Jacob: I didn't really say about the later part!

Shay thinks the foods react at different times, alluding to chemical reaction again, though Jacob questions this idea:

Shay: The sweet now, I feel like the process happened faster than sweet later. Sweet now … like your brain goes faster your taste buds are sending up the food to your brain to figure out that sweet.
Jacob: If it is sweet later, then the process happens the same? Why? And then it takes longer to taste the sweet, Why?
Shay: Because of your taste buds, that is why!
Jacob: (shakes his head) Ava said it happened quicker and slower.

Valencia suggests that there is something different in the actual foods that results in the patterns of faster or quicker sensation of sweet tastes, an idea that interests Ava:

Valencia: It happens how the food grow in the ground, on the bush in or on the bush. The food grow different and then they are different places where the sweet is in them. Or sometimes the people, they put like chemical in it and it tastes different in the, the chemical that they add.
Ava: Why are you tasting these the same? (She indicated the foods in the sweet all the time column) and then these taste different?

Jacob continues, building on Valencia's idea, and Shay finally comes around too:

Jacob: I think that because you probably want to know how it's something sweet at first and then it fades always how they are grown faster or slower makes that food different. They food had stuff in it that makes the sweet taste quicker or slower. Not sweet the whole time because everything that like because I mean everything is organic so there is not chemical stuff in it, it is a natural way of it how it is grown.
Shay: OK, yes, I tried an apple from an apple tree there is not chemical in it, like they grow on the tree. Also these (indicates the sweet whole time column) would taste the whole time because it was without anything extra.

Ava was listening intently, now she speaks, summing up the group's ideas about how to categorize tastes—the process they have been *iterating* on—she presses on the idea that matter is composed of particles too small to see:

Everything that was sweet the whole time, and some things on that list this was like sweet then it goes yummy and then a few minutes later, yuck! … The flavor that the ingredient of sweet, and the flavor was the same at different times, is a similar ingredient that is in all of them. It is part of what was in the growing in there is some things the same and different because they were grown. But the similar ingredient is in the food … somewhere in the food and different in the food.

Jacob: (points to the word "Pattern" on the notebook) "That's the pattern!" (He leans back, triumphant) "The minerals inside the food, that is the same in every one of them."

What purchase does computational thinking provide learners for using the particle nature of matter to understand taste? This final lesson in the set forwarded the practice of computational thinking. The use of the *patterns* promoted an iteration of ideas around the phenomenon of taste and discussion about how this phenomenon has patterns that can be applied to determine similar and different compositions across foods. Here we see students making use of computational thinking to *iteratively* develop beginning ideas around the phenomenon of taste being the chemical reaction to various compositions of particles that make up foods, a deepened understanding arrived at through engaging in the *decomposition* of the phenomenon into smaller parts.

In lessons 1–4, the variance of taste seemed to be an experience that they were not able to deeply refine or iterate their understanding. Instead, the students understood taste as an encompassing experience: a food was good, or it was spicy, or lemony, causing them to consider foods as homologous substances. Computational thinking, especially the practices of *decomposition* and *iteration*, enabled the group to rework the phenomenon of taste and smell as being a phenomena with *multiple* steps, deepening the idea of the particle nature of matter.

11.10 Discussion and Conclusion

The promise of computational thinking for supporting science instruction has begun to receive more attention (Grover & Pea, 2013, 2018), but additional exploration is needed on how to productively integrate the practices and concepts of computational thinking to support the building of useable knowledge. Little is known about how to support elementary children in computational thinking.

In this case study, we explored how elements of computational thinking were critical in supporting a group of learners in developing knowledge of the particle nature of matter. Like Grover and Pea (2013, 2018), we like to think of computational thinking as several reinforcing practices, and we do not restrict the practice to computer programming. As this study shows, when supported by carefully designed instruction, students can productively engage in various associated practices of computational thinking without having to rely on technology-laden approaches that emphasize programming or coding. This particularly comes through in lesson five. When teachers explicitly support computational thinking practices such as decomposition and iterative refinement, young learners do engage in these practices.

For this case study, we asked *What does the practice of computational thinking afford students making sense of phenomena related to the core idea of the particle* *nature of matter?* Our work offers insights into the value of computational thinking for supporting students in sensemaking. The students had already engaged in the practices of asking questions, developing a model, and conducting an investigation with data analysis. However, they had reached a point of relative immobility, alternating between Johnson's (1998) levels of *matter being homologous* (i.e., "The aroma is the food") and *matter containing particles* (i.e., "There are minerals in the food"). After using various practices associated with computational thinking, students made progress in their shared understanding of particle nature of matter (i.e., "The flavor that the ingredient of sweet, and the flavor was the same at different times, is a similar ingredient that is in all of them"). The students did not have the language yet to express the idea scientifically, that indeed goji berries and dates contain sugars (fructose and glucose) and that these chemicals form *part of the matter* that makes up these foods. These ideas are beyond what is expected at the fifth grade level. However, our work shows that the groups were wading into the territory of the third level in Johnson's (1998) progression, *matter is composed of particles*, and also the fourth level—that this composition is related to the properties of that matter, specifically taste. This is an appropriate level of understanding for students to develop at this grade level as suggested by the *Framework* and the NGSS.

In this case, computational thinking was particularly helpful in moving the focus group students squarely along the progression of understanding. Group 5's interactions show the beginning of a trajectory to using computational thinking, but significant challenges remain in terms of how to sequence student engagement in building on early experiences while also leveraging DCIs. Aspects of computational thinking may prove more useful for some sets of science ideas (DCIs and CCCs) than others. Further, the appropriate progression for computational thinking may depend on purposeful integration with a specific set of science ideas. Given the limited scope of this work, our results only suggest limited insights, but they do offer a glimpse of the value of computational thinking in supporting learners in making sense of phenomena.

In STEM careers, professionals must be adept in iteratively using their science knowledge and in refining practices to accomplish goals, reflecting a knowledge-in-use perspective (Harris, Krajcik, Pellegrino, & DeBarger, 2019; Pellegrino & Hilton, 2012). To accomplish a scientific aim, such as answering a question about a natural phenomenon, the three dimensions must be practiced and honed together. Project-based learning provides teachers a way to more authentically integrate this into the classroom and can be used to better inform teaching that can operationalize three-dimensional learning.

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