Preservice Science Teachers' Intentions and Avoidances to Integrate Computational Thinking into Their Science Lesson Plans for Young Learners

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Abstract

In this study, we described a curricular module on computational thinking (CT) integrated within an undergraduate, senior level elementary science methods course, and developed insights on elementary preservice science teachers' (PSTs) thoughts, feelings, and actions about CT integration. Our research question was: "*Following participation in an involuntary policy driven curricular module on CT, what is the nature of PSTs' intentions and avoidances as informed by their thoughts, feelings, and actions about the innovation in their elementary science classrooms?*" Three major findings were that PSTs 1) expressed an intention to integrate CT in their teaching and not avoid it, since they thought and felt that CT supported evidence-based science teaching practices and offered opportunity to increase their students career interest in STEM. That is, PSTs thought that the CT integration offered them the opportunity to teach science in a policy supported manner to all their students, including those traditionally underserved in STEM; 2) thought that opportunities to engage in CT in science would benefit their young students due to their use of technological tools to teach CT. Furthermore, they felt that CT made science more fun, interesting, and engaging, as well as cognitively challenging because of the need to think in a new way about science and engineering; 3) varied in their reasons for integrating CT in their practices and in their actions to integrate it in their classroom science lesson plans. Approximately half of the participants attempted to integrate CT due to polite compliance (termed "Visitors to CT Land") and half attempted it due to a personal commitment to promote a new way of thinking in science that included CT (termed, "Good

Citizens in CT Land”). PSTs in both groups varied widely in the scope and accuracy of their lesson planning and instruction of CT. Discussion focused on the role of affordances but also challenges in PSTs thinking, feeling, and acts of integrating policy driven innovation in pedagogy, specifically the CT innovation. Findings have implications for the design and instruction of science methods courses that seek to integrate effectively CT. Additionally, consideration of the use of lesson plans as evidence for the integration of CT in science instruction was the focus of an addendum to the study.

Keywords: Computational Thinking, Teacher Education, Science Education, Elementary

Introduction

The rationale for our research was driven by policy and theory[2]. It is policy driven because our state in the USA was an early adopter of The Next Generation Science Standards (NGSS) (NGSS Lead States, 2013), which have been adopted by 19 US states and the District of Columbia (DC) (which means approximately 35% of the USA’s K-12 school population are being guided by the NGSS). In addition to the NGSS, another influential STEM educational policy document in the USA (e.g., Committee on STEM Education, 2018) places attention on students’ need to develop “computational literacy” (p. 21). The NGSS includes computational thinking (CT) as a Core Science and Education Practice (SEP). Only two NGSS standards in the elementary grades (5-PS1-2, Matter and Its Interactions; 5-ESS2-2, Earth’s Systems) explicitly incorporate the Using Mathematics and Computational Thinking practice, and only at the upper elementary (5th grade) level. Many instances exist in the NGSS that explicitly incorporate CT in

[2] For additional information on the project in which this study is embedded, see McGinnis, Ketelhut, Hestness, Jeong & Mills (2018; Hestness, Ketelhut, Plane, Razler & McGinnis, (2018).

middle school and high school grades. This policy driven innovation to include CT in science education has spurred immediacy in the field's interest in learning more about CT, including how to prepare science educators (teacher educators and classroom practitioners) to teach CT to learners and especially those typically underrepresented in computer science and STEM, in general. The following overall question guided our research project: What strategies are most effective in integrating computational thinking into elementary preservice teachers' (PSTs') pedagogical preparation experiences in science in order to cultivate and improve access to CT for all students? For this study, our delimited research question was: *Following participation in a policy driven curricular module on CT, what is the nature of PSTs' intentions and avoidances as informed by their thoughts, feelings, and actions about enacting the pedagogical innovation in their elementary science classrooms?*

Theoretical Perspective

Theoretically, we were guided in our study of pedagogical innovation in teacher education by an attitudinal and belief change model, the Cognitive-Affective Model of Conceptual Change (CAMCC) (Gregoire, 2003). The CAMCC provides an interpretative framework designed to explain how teacher educators react (think, feel, and act) in response to policy driven innovation/reform—in this instance to the inclusion of CT in elementary science and engineering education. The model suggests that if an individual sees the innovation/reform as a (desired) challenge and responds with intention (i.e., acts) there could be a belief change. However, if the individual sees the innovation/reform as a threat and responds with avoidance then the result is likely to be superficial or no change in beliefs. Furthermore, self-efficacy is considered to likely mediate the individual's response. The role of mastery experiences (Bandura, 1997) is an important component in the model, as they are seen as increasing the individual's self-efficacy and leading to an increase in the individual's embrace of the innovation/reform. As a result, the story we tell is not a misconceptions or evaluation investigation (got it vs. didn't get it right) but a more nuanced interpretation of how a research team used relatively uncommon for the field theoretical frameworks and an iterative qualitative coding methodological strategy to gain insight into how PSTs make sense of a profound policy driven pedagogical innovation in science education, teacher generated integration of CT in elementary science classroom lessons.

Background and Context of the Study

The pervasive use of computation, from automation to artificial intelligence and machine learning, is acknowledged as changing how scientists, engineers, and citizens study and interact with natural phenomena. However, CT remains a relatively new consideration in science education in the USA. In 2006, Wing asserted that CT was a new form of analytical literacy (diSessa, 2000; Wing, 2011) to join the other essential literacies for the 21st Century such as of reading, writing, and mathematics. There is optimism within the computer science and science education communities that CT can provide students with the knowledge, dispositions, and tools needed to be successful in a rapidly changing, computation-based world (CSTA and ISTE, 2011; NRC, 2010). Presently, however, no consensus definition of CT exists which adds uncertainty in how CT should be presented to educators and learners (see, for example, Barr & Stephenson, 2011; Weintrop et al., 2016). The goal of such an innovation is to equip teachers with the pre-requite "CT knowledge and skills so they can be applied to the curricular context" (Yang, Mouza, & Pan, 2018, p. 368). As a result, while recommendations are increasingly made to include CT in PSTs' pedagogy preparation methods (Yadav, et. al., 2017) there remains uncertainty as to how to implement and accomplish that goal. Therefore, research in this area is imperative to conduct for the field to advance. In this study, we explored how to effectively integrate CT into elementary PST science methods course.

During this study, the PSTs were in their final year of teacher preparation and spent considerable time in the school environment in a supervised yearlong practicum, including preparing subject matter lessons and teaching elementary students. To investigate our research question, we studied a voluntary sample of PSTs (N=39). The majority were White women in their early 20s. Approximately 20% were Hispanic. There were White three males in their early 20s. They were placed for the semester in in eight different public elementary schools in a professional development school network. Their schools varied by multiple diversity and socioeconomic variables, with some primarily constituted by African American students, others with Hispanic student, and few by primary White students. Field placements were the following: eight were in first grade; nine were in second grade; eight were in third grade 10 were in fourth grade and four were in fifth grade.

We analyzed the PSTs' responses to a reflective prompt that asked them to reveal their thoughts and feeling to the policy driven CT pedagogical innovation. We also had them draw themselves twice; the prompt was to show themselves integrating CT in their science teaching pre- and post-CT module instruction. Finally, we analyzed their end of semester lesson plan course assignment that required them to integrate in their NGSS aligned instruction at least one CT practice of the four taught in the CT module (Data Practices, Models and Simulations, Computational Problem-Solving, Systems Thinking).

The same instructor (first author McGinnis, a tenured professor of Science Education) with extensive experience in designing, teaching, and studying various innovations in science teacher education (multicultural science education, McGinnis (1995), Smith & McGinnis, (1995), McGinnis & Pearsall (1998); science education for students with special needs, McGinnis & Nolet (1995), McGinnis (2003); climate change education, McGinnis, Hestness, & Riedinger (2011), Hestness, McGinnis, Riedinger, & Marbach-Ad, 2011), Hestness, McGinnis, & Breslyn (2015), Hestness et al, (2014), McGinnis & Hestness (2017), Hestness et al.(2017); informal science education, Riedinger, et al. (2010), educational technology and computational thinking, McGinnis (1996), Breslyn & McGinnis (2019)) taught them as identically as possible throughout the fall semester, 2017 in two separate sections of the same science methods course in which they were enrolled. He taught them the first session of the CT module lessons, the second was taught by a faculty member in Computer Science, and the third was taught by co-author Hestness. The two courses met on Tuesdays and Thursdays for 13 weeks in 2 hours and 45 minute sessions. See Table 1 for details of the CT module (which consisted of three consecutive class sessions and extended over 8 hours of instruction in a course that totaled 40 hours of instruction).

Class session	**Description**
1. Introduction to STEM and the NGSS	PSTs are introduced to CT as a Core Science and Engineering Practice in the NGSS with the potential to help prepare all students – not just those with access to specialized technology or computer science courses - for STEM careers if they choose. They explore CT characteristics

	(ISTE/CSTA, 2011) and their applications to the elementary classroom.
2. CT Challenges through Robotics	PSTs engage in a hands-on CT experience solving programming challenges with LEGO Mindstorm, KIBO, and Code-a-Pillar robotics tools. They reflect on the CT characteristics they employed, and anticipate the benefits and challenges of engaging elementary learners in CT.
3. CT Integration in Elementary Science through Citizen Science	PSTs engage in a citizen science activity (Cornell Lab of Ornithology's Celebrate Urban Birds https://celebrateurbanbirds.org/) and are introduced to taxonomy of practices for the inclusion of CT in science education (Weintrop et al., 2015). They identify the CT practices and science content embedded in the activity, in preparation to develop their own CT-infused science lessons.

Table 1. Overview of the CT module within the Elementary Science Methods course

The researchers employed a qualitative methodology (Miles, Huberman, & Saldana, 2014) to guide their collection of and analysis of data. The goal was to collect data seamlessly in the course that could inform the need to understand how the PSTs thought, felt, and acted in response to the NGSS policy driven CT innovation.

Research Design

Our implementation of this design based-research model (DBR) guided methodological refinements as well as the implementation of the science methods course. DBR is a flexible, yet systematic, methodology that is frequently used to iteratively develop and test innovations in learning contexts. DBR takes into account the complex nature of studying teaching and learning and allows for a fuller analysis of emergent finding (Cobb, et al., 2003), and supports a collaborative relationship between participants and researchers (Anderson & Shattuck, 2012).

Data Collection

We designed and implemented a three-class-session CT module within an undergraduate Elementary Science Methods Course. We observed and collected field notes on PSTs' (N=39 participation in the module. Table 2 outlines the data collected to gain insight into PSTs' beliefs about CT integration following their participation:

Data Sources/ Conceptual Dimensions	**Description**
Drawing with and explanation prompt Conceptual Dimensions: Thoughts and feelings.	In response to two drawing prompts with explanation requests administered in class (pre- and post the CT module) PSTs described their understandings of CT and illustrated their views how CT could be integrated into science teaching.
Written online reflections/ Conceptual	In response to an online reflection prompt, PSTs described their thoughts and feelings of CT and anticipated benefits/challenges of CT integration, and PSTs gave examples of how CT practices could be

Dimensions: Thoughts and Feelings)	integrated into science teaching practices
Lesson Plan/ Conceptual Dimension: Actions	A major end of the semester assignment required the PSTs to design, teach, and reflect upon a science or engineering structured lesson for elementary students that required the PSTs to select and integrate at least one CT practice as they thought appropriate.

Table 2. Data sources

Analysis

We began our analysis by applying the CAMCC (Gregoire, 2003) as an analytic lens to identify the reform message underlying the CT module. We summarized the reform message as the following: Preparing students for future study and potential careers in STEM fields requires experiences with CT starting at a young age. At present, opportunities to develop CT are often not equally available for all learners. In response, a new reform innovation in science education (NGSS) requires the inclusion of CT in science for all learners, which has profound implications for the teaching and learning of science. Next, over the semester we analyzed PST thoughts, feelings, and actions in response to this reform message. We were informed by prior studies on teacher beliefs regarding implementation of policy driven pedagogical innovations (especially, McNeill et al., 2016). Using qualitative analysis methods (Miles, Huberman, & Saldana, 2014), and applying a values coding approach (Saldana, 2014), we examined our data toward the goal of describing the nature of PSTs' thoughts, feelings, and actions about their intentions and avoidances of CT integration in their elementary science classrooms.

In considering how to manageably approach our initial analysis of our data set, we decided that we most were interested in how the PSTs had approached integrating CT in their lesson plans that they taught to their elementary learners in the public schools. Individually, the five researchers read through all the lessons plans (N=39) and met to share our reactions. A central observation that emerged in our discussion of how we viewed how the PSTs on the whole integrated CT in their lesson plans was that they all seemed to be conforming and not avoiding it, that they varied in their confidence level of enacting the innovation, and a significant number were confused as to how to accurately conceptualize or integrate CT in their lesson plans. We next brainstormed to identify what differing potential analytic categories, themes, might represent the differing types of CT integration attempts the PSTs made in the lesson plans. The list of themes with explanatory definitions that emerged from discussion among the researchers follows:

• Theme 1: "*The Naysayer PST*": The PST stated she did not attempt to integrate CT in the lesson plan and gave as an explanation for that decision that significant barriers existed (e.g., the young age of the learner) that she could not be overcome;

• Theme 2: "*The Slight of Hand PST*": The PST attempted to minimally fulfill the CT integration requirement (e.g., inclusion of any data collection activity.

• Theme 3: "*The Good Citizen PST*": The PST attempted to integrate CT with some success; oftentimes with the PST stating she held low confidence on the accuracy of the CT integration.

•Theme 4: *"The Easy as Pie PST*": The PST integrated a minimal amount of CT, e.g. only data collection, and claimed she was very confident about how to effectively integrate CT

•Theme 5: *"The Star CT PST":* The PST Integrated CT effectively (accurately and richly) with claims of much confident in an understanding CT.

•Theme 6: "*The PST who did not fit well any of the other categories*": The PST integrated CT in unanticipated ways compared to the other 5 themes.

Procedurally, the research team each examined individually all the lesson plans to code them using the provisional analytical categories, themes, as defined. In instances when the reviewer thought the lesson plan did not fit uniquely in any one analytical category, the reviewer had freedom (with explanation) to place it in multiple themes. The Researchers cross checked and coordinated categories with ongoing data analysis conversations. The frequency of lesson plans for each category follows:

• Theme 1, "*The Naysayer PST*" (1 was coded secondarily as theme 1; it was also coded primarily as theme 2). In the lesson plan the PST made the claim she could not attempt integration of CT in her lesson plan's topic although her inclusion of data collection in the lesson plan could arguably be viewed as evidence of CT integration.

• Theme 2, The "*Slight of Hander PST*" (11 coded in theme 2, with 4 coded in theme 3, and another in theme 6)

Sample analyst's comments for coding the lesson plans in this category included:

"The PST seemed to be basing her explanation of how CT was included on an insufficient understanding of CT (that it's planning and carrying out an investigation... which students did not really do in the lesson."

“The PST said she could have done more, she mostly was focused on teaching the content; not sure this lesson would have been any different from any inquiry-based science lesson if CT integration were not assigned.”

“The PST’s explanation of CT integration is based on an incorrect understanding of CT data collection.”

“The PST’s explanation is just not a correct application of CT practices (e.g. modeling by drawing shoes, data collection by observing shoes.)”

“I think the data collection and analysis comes from an accurate understanding of CT; it's the easy to identify set of practices, and it was successfully integrated in this lesson. Her mention of systems and thinking in levels in the reflection seems unjustified.”

*“*Seems like CT in the lesson was an afterthought, but the PST states she is confident on CT integration.”

• Theme 3, *“The PST as Good Citizen”* (13 were coded in theme 3, five analysts shared categories with theme 3, two with theme 2, two with theme 4, one with theme 5).

Sample analyst’s comments for coding the lesson plans in this category included:

“She stated that students usually don't get to collect data themselves (the teacher usually does this), so it does seem that she made an effort to give students a CT opportunity.”

“I am unsure if the PST has confidence in her understanding of CT practices other than data practices/”

“The PST acknowledged that CT implementation was unsuccessful.”

"The PST is semi-confident that she did CT. She totally made up a CT practice."

"The PST acknowledged that the implementation of CT was not well done."

"I think it was a vocab issue; she was doing algorithmic thinking but talked about other CT concepts instead."

"The PST claimed she was able to successfully include CT. However, the way she claimed CT was not unique to CT."

"I think the data collection and analysis comes from an accurate understanding of CT; it's the easy to identify set of practices and was successfully integrated. The mention of systems and thinking in levels in her post lesson reflection seems unjustified."

"The PST has articulated well understanding of the CT practices that she implemented in the lesson plan. The most valid CT practice used was the collecting of data. The modeling was not exactly what is meant for CT, but could be a *proto* CT version. The system CT practice (communicating) is the most interesting to document for young learners."

"The PST claims some success in incorporating CT, but it does not go beyond the typical inquiry process."

"The PST gave it a try to include CT by use of a problem and data collection, but then she admits the limited nature of its integration."

• Theme 4, *"The Easy as Pie PST"* (8 were coded by this theme, two shared, one with theme 2, one with theme 3)

"CT was present, but overestimated how much."

“The PST seemed confidence in the implementation of CT and knowledgeable about the CT practices the students used.”

“The PST showed confidence in the lesson plan and the implementation of CT but acknowledged that CT practices were not recognized.”

“The PST stated, “my students definitely took part in CT throughout this lesson.” This reflects to me the PST's confidence in his implementation of CT.”

“The PST is very confident in stating she integrated CT but I do not see evidence that she did integrate CT.”

“The PST is very confident in having integrated CT in her lesson. Although, I believe she is confounding "planning and carrying out investigations" with CT practices. She also appears to believe that the demonstration is a "simulation," which it is not. There is some modeling in the drawing of an object with forces acting on it, but she does not cite that as CT.”

• Theme 5, *“The Star CT PST”* (3 coded it theme 5, one with theme 3, one with theme 4, and another with theme 6)

Sample analyst’s comments for coding the lesson plans in this category included:

“The PST makes all seem straightforward in a very positive way. [However, the reviewers differed on if the CT claims were accurate].

“The PST claims, “I was able to successfully include CT." While the two claimed CT concepts were included, they are not unique to CT and seem to show how general science is taught.”

“The PST used a simulation for problem solving which did engage students in CT, but this seemed like more of a product of the curricular resource chosen (is this in their curriculum already, not selected by the PST?) rather than the PST's efforts to creatively incorporate CT.”

• Theme 6. “*The PST who did not fit well any of the other categories*”: No one coded a lesson plan first as theme 6, two coded it secondarily.

The research team next met and discussed the results of the provisional coding of the lesson plans that was used the six thematic analytic categories. The discussion ultimately focused on the issue of grain size (that is, having a multitude of themes rather than a fewer number for an exploratory study). Based on the results of the research team assessments with six thematic categories, all of which received multiple differing coding by the research team, the research team decided to a consider a larger grain for the analysis with fewer analytical thematic categories as a way to increase agreement among the analysts.

Upon discussion, the consensus view was that the lesson plans could be categorized effectively by use of two thematic analytic categories if metaphorically the PSTs’ could be viewed by their enrollment in their elementary science methods course as travelers entering a new conceptual “land of CT” in science instruction as guided by the NGSS. If so, how they reacted to that pedagogical demand, especially in how they acted to that requirement, whether politely compliant or willingly in support with the innovation could be credibly coded. Within each category, variations in which CT practices were integrated and to what extent they were accurate could then be noted and examined for patterns. The two analytical categories that then emerged during the researchers’ discussion of the matter if our PSTs were considered as travelers taken to a new conceptual land of CT[3], were the "Visitor to CT Land" and the "Good Citizen in CT Land." The definition of the two categories follows:

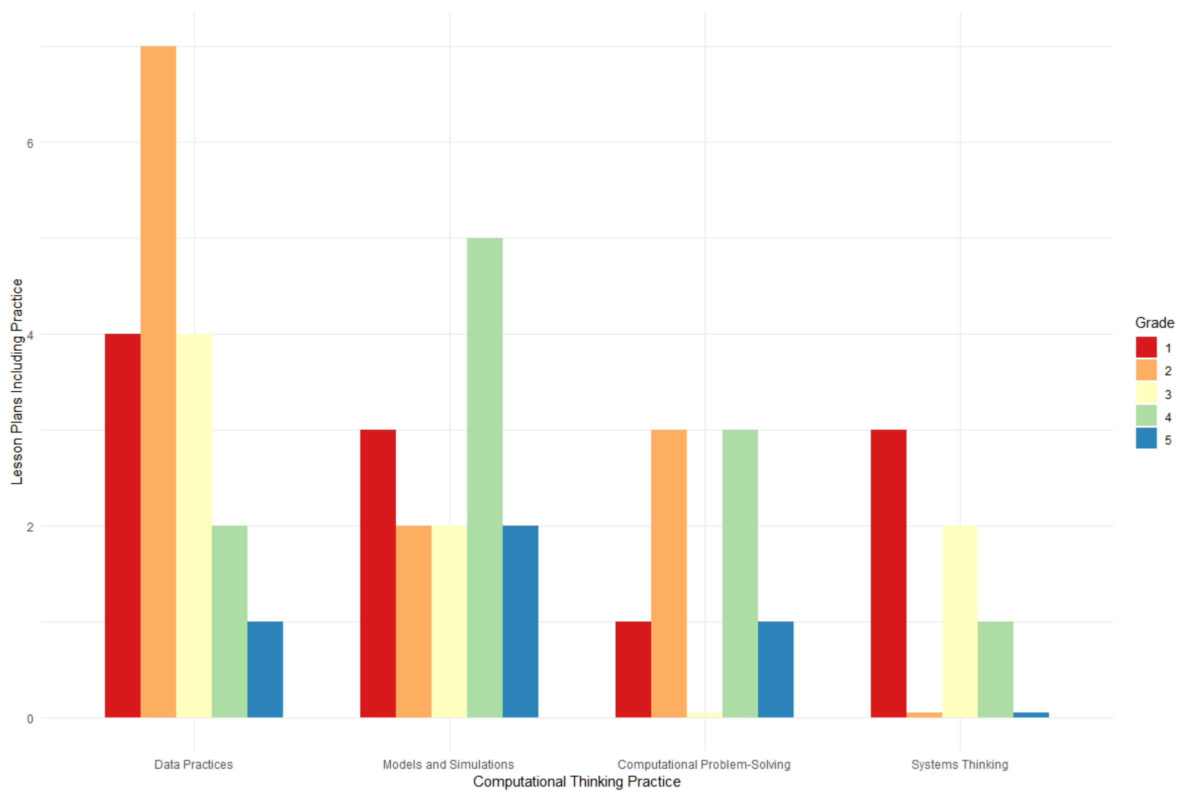
Theme 1: *The Visitor to CT Land*: The PST was viewed as an educator in preparation taken by the course instructor to CT land by virtue of being enrolled in the elementary science methods course. The PST expressed *polite compliance* in considering the integration of CT in NGSS science and engineering. As a result, the PST acted willingly, but tentatively, to fulfill the lesson assignment's expectation of what a teacher with this professional obligation might include in a science lesson plan for elementary learners.

Theme 2: *The Good Citizen in CT Land:* The PST expressed and acted willingly with an accepting mindset to being exposed to the pedagogical ideas in the land of CT. Such a perspective was evidenced by the PST's expressed confidence in an understanding of the various CT practices and in their attempt to include an array of them in their science lesson plans for elementary learners.

Using these two themes the research team each coded a selection of lesson plans assigned. Each lesson plan was coded by two reviewers. If there were disagreement between the reviewers that

[3] In research on geography education, the concept of "spatial thinking" has increasingly become recognized as critical as a perceptual lens to interpret learners' understanding of sites or places in which an individual resides physically as well as mentally (including metaphorically) (Stevens, Godwals, Jin, & Barett (2016). In our study, we considered the CT pedagogical innovation as a mental (metaphorical) place that has its own boundaries and practices (Akkerman & Bakker, 2011). As such, the instructor of the PSTs' elementary science pedagogy courses served as a guide for the PSTs in traveling to a new conceptual site or space, which we termed "the land of CT." The PSTs were introduced to its features, i.e., the differing practices and how they added to traditional considerations of science and engineering), and were asked to incorporate the CT practices which they found of value in their NGSS science teaching practices with their elementary students. None of the PSTs expressed avoidance of the CT practices that they learned about in that new land, but there was variation in the scope and accuracy of how they integrated the new way of thinking of science as including CT. In our sample, the PSTs were either politely compliant to act on including CT in their science lesson plans or they expressed that they were willingly drawn to integrating the CT practices as they understood them.

could not be negotiated to a consensus code, a third reviewer would be assigned to break the tie. Of the 39 lesson plans, the initial coder agreement was approximately 90%. After discussion and negotiation, the coder agreement increased to 100%, so no third reviewer was needed to break any ties. The frequency of PSTs in the *Visitor to CT Land* category was 17 (47%). The frequency of PSTs the *Good Citizen in CT Land* category was 19 (53%). The research team concluded its analysis of the data by identifying the CT practices the PSTs claimed to integrate in their lessons and made some tentative assessments of the appropriateness, quality, and accuracy of such actions. See Table 3 for the distribution of CT practices the PSTs integrated into their science lesson.

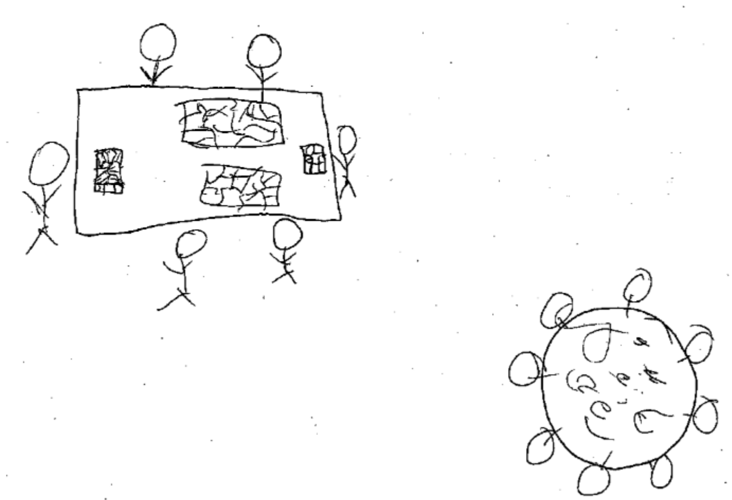


To illustrate each analytical category, a focal case study is now presented.

Focal Case Study One: Cheryl[4], The PST Visitor to CT Land

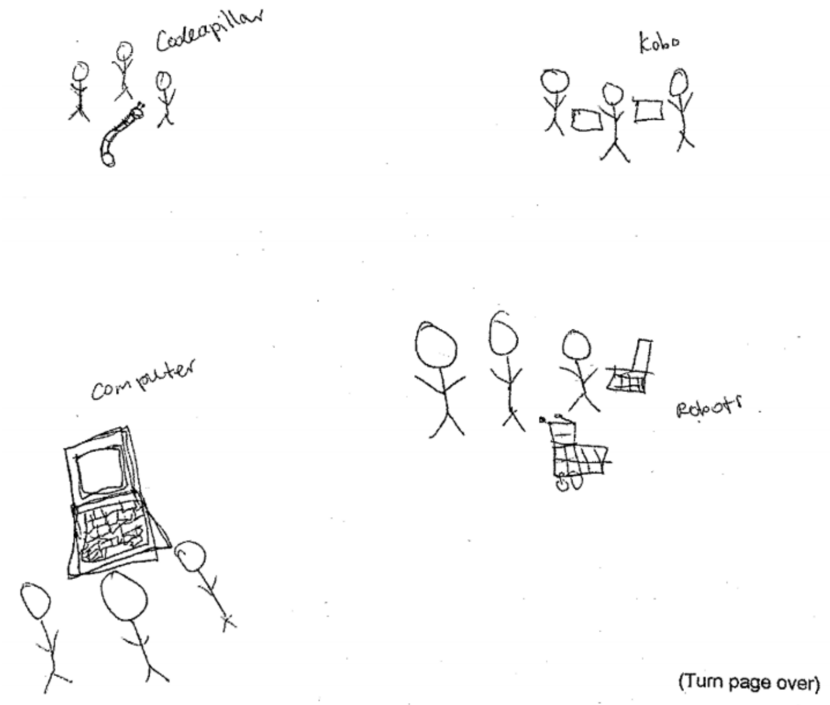
Thoughts, feelings, and actions of CT. Before and after we implemented the CT module, the PSTs were asked in a class session to respond individually to the following drawing prompt: "Draw your students engaged in computational thinking while learning science." In addition, on the back of the data collection sheet, the PST was asked to respond to these two questions: 1. What does computational thinking mean to you? 2. What did you intend to communicate through your drawing?

Cheryl's pre-CT module drawing:



Cheryl's post-CT module drawing:

[4] Pseudonyms are used for all PSTs' names in this study.



Cheryl's explanations that accompanied her drawings:

Pre-module:

Directions: Please respond to the questions below, including as much detail as you can.

1) What does computational thinking mean to you?

Computational thinking means critically thinking about how to solve problems using mathematical strategies.

2) What did you intend to communicate through your drawing on the reverse side of this page in response to: "Draw your students engaged in computational thinking while learning science"?

I intend to communicate a hands-on approach. Students can use computational thinking to solve hands-on problems rather than simply problems on paper.

Post-Module:

1) What does computational thinking mean to you?

Computational thinking means using technology to learn, but it also means thinking in ways that technology would in order to generate solutions. It involves using computers in learning as well as other educational technologies. However, it also involves thinking in algorithmic ways, identifying patterns, and problem-solving in ways that computers do.

2) What did you intend to communicate through your drawing on the reverse side of this page in response to: "Draw your students engaged in computational thinking while learning science"?

I intended to communicate what I learned through the course this semester. I appreciate that I was able to practice using educational technology because it helped me understand the importance of introducing this hands-on learning to my students. I also wanted to show different groups of students working with different tools because in a realistic classroom setting there will be students who gravitate toward different tools.

Researchers' Commentary

An examination of Cheryl's drawings and explanation suggests a story of a PST starting from a relatively non-existence level of familiarity with the notion of CT (her pre-drawing and accompanying explanation show no evidence of the concept) to some limited progress over the course in an understanding of CT. In particular, her post drawing shows her learners interacting with the educational technology tools that were used in her CT module. However, as seen in her accompanying explanations of her thinking about CT, she presents strong feelings for the use of educational technology tools such as robots, that could support her strong beliefs that science should be collaborative and active based, but no understanding of CT practices that the educational tools could apply.

For her CT online reflection on CT, Cheryl stated what she understood of the four CT practices presented in her elementary science pedagogy course, and what she thought and felt about the CT pedagogical innovation. As she stated,

*"1. **Data Practices**:*

For collecting and analyzing data, I would have students utilize Microsoft Excel. This tool would work best in a fourth or fifth grade classroom. Excel is useful for students who already understand the concept of graphing and want to represent their findings on a computer. It allows students to input their x and y values and shows how they would be represented graphically. For example, to analyze plant growth, students can collect data over time from a plant in the classroom and they can plot these numbers into an Excel spreadsheet. Students will then be able to use the software to digitally create a graph. They can insert this graph into another software, such as PowerPoint or a Word document.

Modeling & Simulation Practices:

Excel makes it easy for users to represent their data in various forms. Students can choose to represent their findings on a line graph, bar graph, stem-and-leaf plot, etc. They can even choose more than one of these representations. Because it is simple to manipulate the data, the students can assess which representations are most accurate to the information collected.

They can also experiment with changing data points and seeing how the new data influences the appearance of the graphs.

Computational Problem Solving Practices:

Provide students with a real-world problem. The mayor of the city is debating on whether to spend money on new plants around the city or a new fountain in the center of town. He wants something that will make the town look more beautiful, but he wants it done quickly. Students should prepare a presentation that displays which plants grow the fastest, how they know, and why the city should plant them instead of the fountain. This task will allow students to determine which graph would be the best representation of the data for the purpose of convincing the mayor. It will also allow them to critically think about how they can use data to defend an argument.

Systems Thinking Practices:

Have students explore how changing one factor would affect the data set. Give them a list of data points for changes such as special fertilizer, rain, temperature, etc. Students can plot the data into the graphs on Excel and draw conclusions about the effects of these factors on the plant growth."

Cheryl's Professional Reaction to Integrating CT in Elementary Science Education

Cheryl stated: *"I think I have grown throughout this semester as a teacher and as a learner. I have begun to more carefully consider the needs of ESOL students and students with special needs as part of the learning experience. Even in my placement now, I have been able to recognize when my students with autism are unengaged and are in need of an alternative* *teaching strategy. I have also noticed the importance of diagnostic and formative assessment for students as a proactive measure to ensure learning is taking place.*

For me, the most useful part of computational thinking is the visual representations. ESOL [English as a Second Language] *students and students with special needs greatly benefit from digital graphics that can be easily manipulated. In the article "Alternate Assessments for English Language Learners," the authors describe the importance of allowing ELL students to convey their understandings in ways that do not require command of the English language. Instead, they say it is useful to allow students to draw pictures to show understanding. There are many applications on computers that allow children to create graphics as an assessment for learning. My mentor teacher uses Flipgrid, an online video platform, as well as many Google Chrome extensions for students to display their learning gains. The best part about these applications, in my opinion, are that the content can be easily deleted, altered, moved to another location, or other changes that the students want to make. It provides flexibility for these students who may feel restrained by other types of assessments.*

I think having assessments that keep students engaged in thinking are essential for progressing student learning. While some may argue multiple-choice standardized testing is useful for widespread data collection, there is little scientific exploration and sharing of original ideas. As mentioned in the document "A New Vision for Teaching Science," students need to understand that science is "an exercise in building and revising theories," not concepts that are fixed. The activities that I mentioned above allow students to demonstrate their understanding of scientific thinking without constraining them to specific concepts.

Additionally, computational thinking practices allow for hands-on learning, which is beneficial for students with special needs. In my classroom now, there are three students who are *diagnosed with autism. Like all children, these children's forms of autism are also unique. I initially struggled with ideas on how to keep them engaged and how to aid in their learning. I felt like the paraprofessional was not doing enough to make sure that the students were involved in the learning. I decided to take it upon myself to offer them alternative activities. I quickly noticed that these students learned much more quickly when presented with kinesthetic learning opportunities. As mentioned in "Teaching Science Learners with Special Needs," assessment material that is hands-on will allow these students to demonstrate that learning is taking place. I can see my students with autism being highly engaged with tools such as the Code-a-pillar and the Kobo.*

Computational thinking allows for self-exploration. It allows students to learn sensitive topics in a way that is self-reflective and analytical, as compared to explicit instruction. Furthermore, I think that computational thinking practices provide students with a sense of control over their learning, which also assists in teaching sensitive topics. The problem I foresee when trying to implement diagnostic and formative assessments is the pressure by administration to focus on summative assessments. I have seen within my school now that the county is adamant about standardized testing at the end of the year. However, I think that I can use formative and diagnostic assessments in my own classroom throughout the entire school year to determine where areas of learning are taking place versus where they need further instruction. It will be useful for my county as well because I will be able to ensure that my students are performing and growing at a developmentally appropriate rate."

Researcher's Commentary

A careful examination of Cheryl's reflective comments offers opportunity to make inferences of her thinking and feelings for the CT innovation. Emerging from her reflection, in particular, is her commitment to active based science instruction with an equitable lens. She underscores her positive feelings of care for all learners by how she sees the visual representation of data as result of a CT as beneficial particularly for her students with second language and special needs. Missing, however, from her comments is evidence that speaks to a growth in her understanding of CT practices, beyond a surface recognition of the types of CT practices, and how to apply them as envisioned by the policy driven documents for the CT innovation. In her application of the CT practices (from Weintrop et al.'s framework), Cheryl applies her own understanding of the terminology to classroom practice, which in most cases does not capture computational thinking. For example, in data practices, Cheryl discusses Excel, which is a tool she is likely familiar with and relevant to CT data practices. However, it is unclear how Excel also applies to modeling and simulation. Additionally, for computational problem solving, she described a vague problem scenario, but does not relate to CT practices, and the same for systems thinking.

Cheryl's Lesson Plan

Cheryl designed and taught a science lesson for her elementary students in which she claimed to attempt to integrate CT as an afterthought (see appendix A for the complete lesson plan). In summary, in Cheryl's lesson plan she sought to teach her students about fossils by a focus on the use of physical models, fossils.

In Cheryl's Post-lesson assessment of her attempt to include CT in her lesson plan she stated,

"I think that I effectively implemented pattern recognition and modeling complex systems. Students found patterns between their leaves, between their leaves and their drawings, and

between their models with real fossils. They were also able to model the process of fossil formation using the tools we could access in school.

Because my students have an array of behavioral needs, I am generally nervous to implement tasks that call for a high attention span. As a result, I made sure to plan tasks that were short but effective. I wanted the students to be able to use modeling to show how fossils are formed, but I knew that using props such as sand or clay would create more distraction than learning. Thus, I researched ways that I could model how fossils formed with easily accessible and mess-free tools.

I believe that my students gained understanding about CT through the connections and patterns they recognized. They used the materials they had in order to connect to the work of professional scientists. They also made their own observations and recognized patterns about the limitations and potential uses of looking at fossils to understand past life on Earth."

Research Team's Commentary

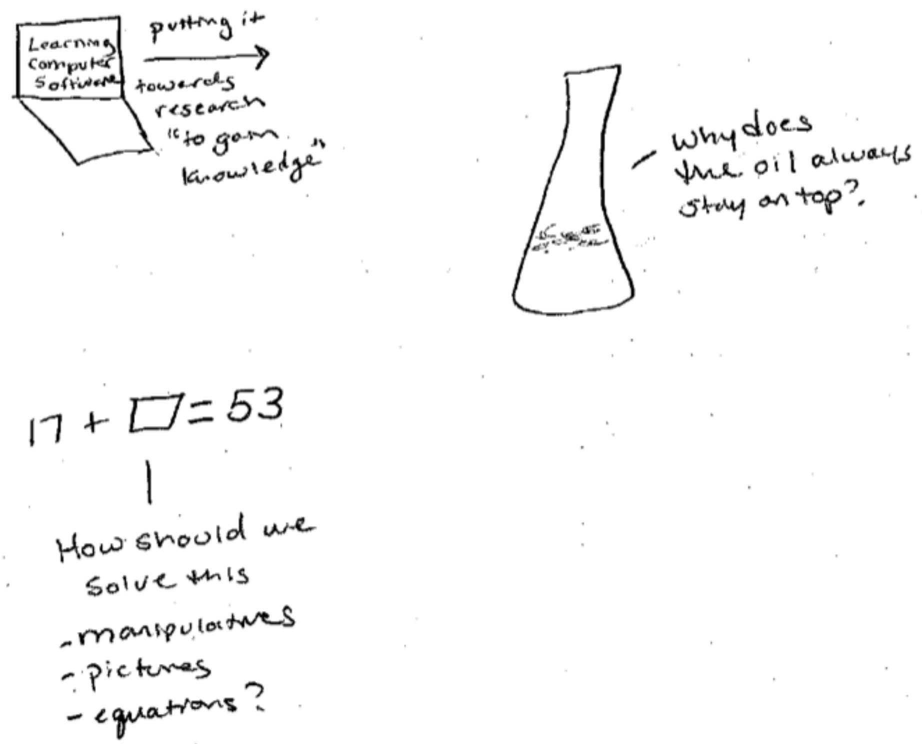
A careful examination of Cheryl's lesson plan shows evidence of a PST minimally and shallowly attempting to integrate CT into science. In her lesson plan, Chery did not identify upfront a CT practice that she sought to teach as required by the explicit direction for the assignment. Instead, Cheryl claimed in her post-lesson reflection, inaccurately, that physical model making was an application of CT modeling; therefore, she claimed she had made a meaningful attempt to integrate CT in her science lesson plan. In addition, Cheryl revealingly stated that she felt it was appropriate not to intellectually challenge her learners to learn science by planning for and insisting on sustained attention on their part that went beyond short active engagement.

Overall, it appears as if Cheryl didn't modify components of the lesson to integrate CT. Rather, she morphed the definition of CT to fit her lesson. She claims students are recognizing "patterns" and "modeling complex systems." Both pattern recognition and modeling (sans CT) in this lesson are weak, and certainly not computationally relevant.

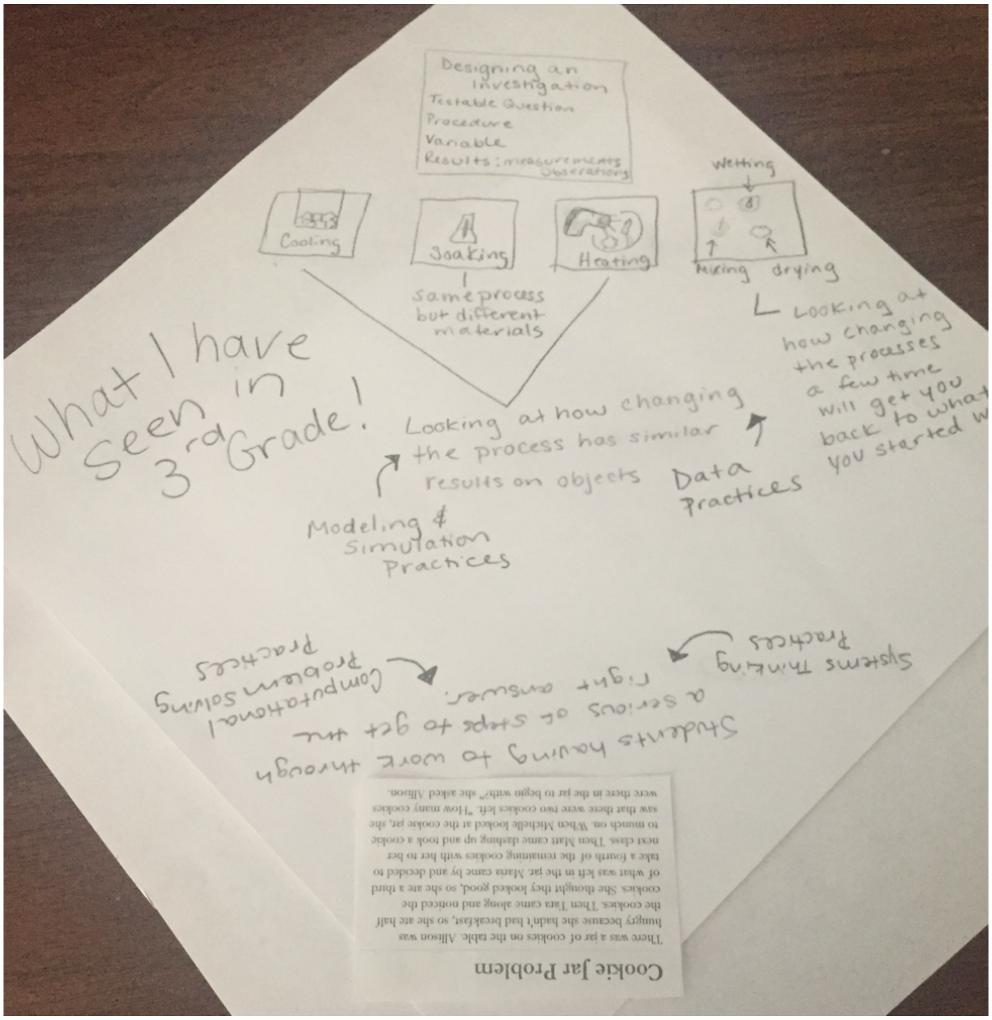
Focal Case Study Two: Brittany, the PST Good Citizen in CT Land

Thoughts, feelings, and actions of CT. Before and after we implemented the CT module, the PSTs were asked in class sessions to respond individually to the following drawing prompt: "Draw your students engaged in computational thinking while learning science." In addition, on the back of the data collection sheet, the PST was asked to respond to these two questions: 1. "What does computational thinking mean to you?" 2. "What did you intend to communicate through your drawing?"

Brittany's pre-CT module drawing:



Brittany's post-CT module drawing:



Brittany's thoughts and feelings for CT:

Pre-module:

1) What does computational thinking mean to you?

Computational Thinking - problem solving skills using science, math, & engineering.

2) What did you intend to communicate through your drawing on the reverse side of this page in response to: "Draw your students engaged in computational thinking while learning science"?

I think students engage in problem solving in many areas of the classroom. I showed different times students have to engage in problem solving?

Post-Module:

1) What does computational thinking mean to you?

Computational thinking is the thinking that is involved in computer programming, but from an education perspective we find that computer programming thinking applied elsewhere. Educators want to highlight this thinking in different areas to increase student readiness for entering a digital age; it also helps students make connections to programing to spark interest and it creates a new purpose to science in our classes

2) What did you intend to communicate through your drawing on the reverse side of this page in response to: "Draw your students engaged in computational thinking while learning science"?

My drawing was to show what activities that I have done with my students that involve computational thinking. A large part of CT and NGSS is designing experiments, understanding how different types of changes can be made in experiments to reflect different results, and understanding how results of experiments help to solve bigger problems. My students this semester engaged in a lot of experiments as they tested cooling, soaking, heating, etc. I also saw a connection to CT in the math courses as many of their word problems have multiple steps in them, multiple solutions, and my class talks about what solutions are most efficient.

Researcher's Commentary

An examination of Brittany's drawings and accompanying explanations presents a story that suggests to us a PST journey of a clever "best guess" interpretation of CT (basing guesses on the use of the word "computation" that brings to her mind computers and numerical calculations) to a more sophisticated understanding of CT and the policy (NGSS) from which it emanates. Her post-drawing and detailed explanation suggests that the PST holds a clear understanding of the CT practices taught in the CT module, the rationale for the inclusion of CT in the NGSS, and a desire to demonstrate how thoroughly she can integrate CT in her science teaching (and other subjects, such as mathematics).

For her CT online reflection on CT, Brittany stated what she understood of the four CT practices presented to her in her elementary science pedagogy course, and what she thought and felt as an emerging professional educator about the CT pedagogical innovation:

"1. Data Practices:

Collecting Data: In my lesson plan, students will practice data collection by recording what materials they used to create the ramp and how long it took to get the object down the ramp. Data collection would be done on a pre-made worksheet so students would remember what to record. First students would record data based on materials; later students can manipulate the data so it is displayed in different ways. Students could change quite a few variables in this investigation in order to have more data collection and to make more conjectures. Students could change the height of the ramps and they could change the objects used to roll down the ramp (adds to creating and manipulating the data).

Creating Data: Students will design their questions about data that they want to collect (i.e. what materials they use for the surfaces, if they want to change the height of the ramps and if they want to change the weight of the object that goes down the ramp). Student's choice will create a *variety in what data is created and it will reflect what students are curious about (more inquiry). For example, students might know that wax paper is smooth and things are meant to fall off of it, so maybe they might be more curious about the plastic wrap; a surface that is smooth like the wax paper, but it is meant to cling to things.*

Manipulating Data: Manipulating data here could help students make different conjectures about the topic and could add extension onto the lesson. After students have tested what they were curious about they can start to make conjectures about friction, force, and motion. They can do this by manipulating the data so it is lined up from fastest trial to slowest or maybe by height of the ramp or maybe by the objected used to go down the ramp. Also, they can begin to answer extension question such as how can you make your object go fast/slower? Or how might people use friction (or possibly cut down on friction) to keep them safe?

Analyzing Data: By manipulating the data in order to answer questions and to make conjectures on the topic students have to analyze the data; meaning they must look over the data until they can try to prove cause and effect relationships between the different variables. They can also raise more questions by looking at the data; what is missing or what should they go back and test.

Visualizing Data: This could be added to the closure or the extension. Whenever students use their data to apply it to other situations they are visualizing data. In the closure the teachers could ask students to apply their data or new knowledge to making a prediction about how different surface would act, does it have a lot of friction or a small amount of friction? Students can also visualize (or apply) their findings to other situations to answer the extension questions, how can you make your object go fast/slower? Or how might people use friction (or possibly cut down on friction) to keep them safe?

2. Modeling & Simulation Practices:

Using Computational Models to Understanding a Concept: Students are constructing a controlled area of friction, force and motion in order to make conjectures about the topic. Students here do not have to a lot of background on the topic in order to be able to understand the models and make their own ideas (good way to support ELL and struggling learners).

Using Computational Models to Find and Test Solutions: Students will generate inquiry question so students will be find solutions to what they are wondering about. Students will find solutions to how fast or slow they want their object to go down the ramp.

Assessing Computational Models: Student will assess computational models as they conduct the trials and analyze the data. During these times students will refer / look at other models to see if their test examined what they intended to examine, as well as identifying any findings that they missed and still would like to investigate.

Designing Computational Models: Students are designing their own ramp based off of what they are wondering about. Students can make the ramp the way that they want in order to focus on friction, force, weight of the objects, or height of the ramp. Students should have a pre-planning stage where they have to draw out their designs so they can explain what they hope to find from their data.

Constructing Computational Models: Students will have the opportunity to create their own models that they designed in order to answer questions that they are wondering about and extension questions.

3. Systems Thinking Practices:

This is the computational thinking practice that I personally think that I have grown most to understand. At first, I was feeling that the word system had to have a very narrow meaning such *as referring to more of a process, such as the water cycle, respiratory system, or ecosystem. Last class I was showed to think about systems as a complex idea that has many parts, such as motion. This is a complex idea because you additionally have to think about how ideas like force and friction fit into this system.*

Investigating a Complex System as a Whole: *In this lesson, the system would be motion and students are investigating the system to see how motion is changed. Prior to this lesson students are not formally taught the definition of friction and in this investigation they are to attempt to define the word based off the investigation designs. Force would be defined before this lesson, but in this lesson students are seeing (physically) how it connects to motion and developing this idea that friction is a force that causes resistance.*

Understanding the Relationships within a System: The system as a whole would be motion and students are more finely thinking about how force and friction relate to motion.

Thinking in Levels: Students have to think about a lot of cause and effect relationships between the vocabulary of motion, force, and friction. Does motion affect friction or does friction affect motion? Levels here means the different steps or components in the system of motion.

Communicating Information about a System: *Students will discuss their ideas constantly though the design and trial stages of the ramps. Students can generate ideas about their designs and discuss with their group members what they are finding, as well as suggest how they would like to design a ramp to find out more about an idea. At the end when they have made conjectures, they can look at different group's designs to see how others made similar or different conjectures.*

Defining Systems and Managing Complexity: *This lesson is designed to mostly to define one part of a system, as it helps to define friction in the system of motion. This helps to give a bigger* *understand of what motion is because we care discovering what things act on motion. This lesson did not include managing complexity, we were not thinking of ways to simplify a system. We have mostly seen this found in lessons that include computational problem solving practices. We did not really define a problem in this lesson.*

4. Computational Problem Solving Practices:

Preparing Problems for Computational Solutions: Students are given the problem or challenge to work with. They are to design their own solution.

Programming: Students get to program a human robot to cross a finish line. There are multiple challenging that students have to get through. Sometimes they are allowed to use certain floor tiles and other times they are not allowed to. Students are to create their own unique code of how they want the robot to complete the mission.

Choosing Effective Computational Tools: Students do not have a lot of choice in tools here. The idea of the human robot was to keep the lesson tools cheap and accessible for most classrooms.

Assessing Different Approaches/Solutions to a Problem*: This is done as a group so group members con discuss together what different approaches there might be; what works, what won't work and what is the most effective solution. Students have to make considerations like how can I get from A to B without stepping on certain squares. Maybe we could tie in math and ask questions about surface area; how could you use the most surface area and land on finish in one minute?*

Developing Modular Computational Solutions: *Students could come up with code abbreviations so their code is not so long and complex to read. They could use symbols to represent a series of steps, such a > meaning go up two turns right and go over two more and < could mean go up two turns left and go over two more. This will create a simpler more modular code.*

Creating Computational Abstractions: *Students have to create abstractions for the different challenges. Students have to understand the important parts to the challenge and be able to communicate them through their program solutions.*

Troubleshooting and Debugging: Students will not always succeed on their first try so they will have to work through their steps to find where the error is in the code. Additionally, students might want to find ways to simplify their code. In this new process, they will more than likely find errors and need to troubleshoot how to simplify without error."

Brittany's Professional Reaction to the Integration of CT in Science Education

Brittany shared her thoughts and feelings toward the CT pedagogical innovation in her response to an online reflective prompt. She stated,

When we first started talking about assessment, we were referring to our own lesson plans in order to critique our own assessments. One problem that I found with my lesson design was that it did not include enough assessment to monitor how students were doing during the lesson. I thought that this was important to include, but also I felt that it was difficult to include. I felt that it was difficult because often in science ideas are new and abstract, so how do you appropriately assess when students are so new to a topic. With all classes having a diverse set of learners it is important to have a diagnostic assessment before units so teachers can know how much is already known in the classroom (Three Types of Assignments). Teachers do not want to teach what is already known, because what learning is gained there, and teachers do not want to miss teaching information because they think that information is known. This can help with heterogeneous grouping so there is someone with strong background knowledge in all groups. Additionally, we do not want to always assume that our ELL and struggling learners will not be familiar with our science topics, here diagnostic tests can help teachers be less judgmental about *who knows what. Conversely, summative assessments will only be used when all the lessons are done on a topic; after lots of practice and explanations has been done, what do the students know at the end of the topic (Three Types of Assignments).*

Formative assessments will help along the way of the lesson so teachers can gage the understanding that is taking place during the lesson (Three Types of Assignments). Teachers can use formative assessments to identify problems in a lesson. For example, if many students are struggling with the formative assessment it can help teachers to see what students are struggling, is it ELL for vocabulary or is it your low math group with the computations? Formative assessments can be data collection worksheets, observations, or exit tickets. To help with some of these problems teachers could include more language supports in their lessons. The NGSS article for ELL encourages teacher to use discussion to facilitate the learning of ideas. The article addresses the use of sentence starters for discussion and allowing for pictures to demonstrate knowledge. Also, in my experience I have seen reading intervention groups pull small readers on science and social studies topics in order to give ELL and struggling learners additional opportunities to have background on these topics and exposure to nonfiction text. To help these students in my class, I think it would be important to talk to the intervention teachers to see if they can use these types of reading matters.

Looking at the NGSS website it will give teachers the topics that they can create lesson plans and assessments for. NGSS gives us ideas on what is the best way to implement formative assessments by examining the "Science and Engineering," "Disciplinary Core Ideas," and "Crosscutting Practices." Looking at these sections it allows teachers to make the considers should we "plan and carry out investigations," "construct explanations and design solutions," "obtain, evaluate and communicate information," or "analyze and interpret data." NGSS *highlights computational thinking with its emphasis on engineering and problem solving practices; many of these ideas listed above include CT. This course has gotten me a lot more familiar with CT and I see where it is embedded in the NGSS, but I question how much CT should be including in all our lessons. You have challenged us a lot to include as much CT as possible in our lessons, which I think is great because students get that style of learning, but I wonder when are times that it makes the lesson too long or maybe even changes the objectives. I look forward to thinking about CT as I learn more about my grade-level curriculum. I will have many considerations about when are the best times to include more or less CT thinking, mostly for time and objective purposes."*

Researcher's Commentary

An examination of Brittany's online comments shows a PST who has developed a robust view of CT. She elaborates confidently and knowledgeably on the key CT practices presented in the CT Module, including subcategories for each, and transfers such knowledge to her vision of science teaching. She portrays the integration of CT in science teaching as enhancing her teaching and as increasing the interest and engagement of her learners in science.

Interesting. Brittany seems eager to integrate CT in her thorough description of practices, but shares a hesitation in her reflection. For the practices, writing about each subcomponent of the four practices gave Brittany's answer more clarity as to the computational relevance. She revealed that she misinterpreted the models to mean physical models, and very interestingly applies systems thinking to motion (in a not very computational way), but the computational problem solving is accurate. And, while she shows a reasonably robust understanding of CT as compared with most of the other participants, it is revealing to note that her application of CT appears like an "add on" to activities she may have already been planning to do (or not do – in the case of the human robot).

Brittany's Lesson Plan

Brittany designed and taught a science lesson for her elementary students in which she attempted to include CT (see appendix B for the complete lesson plan). In summary, in Brittany's lesson plan, she sought to plan and conduct an investigation about liquids by using the process of soaking. We will produce data that will answer a testable question about the physical properties of a pretzel. She explicitly identified the following CT practices to integrate in her science lesson:

"*Data Practices* - Recording / Analyzing Observables Properties - Students will carry out a design to examine what physical properties are and what processes alter physical properties.

Modeling & Simulation Practices - Modeling the process of soaking to understand observable properties.

System Thinking Practices - Understanding (the system of) observable physical properties and how they can change as a process is performed on them. "

Brittany's Post Lesson Assessment of her attempt to integrate CT in her Science Lesson Plan. As Brittany stated in her post-lesson reflection,

"*I have been trying to reinforce to students that things like green, big, smooth are not properties, but descriptions of properties. I intended to overcome the misconception that these are properties. I saw improvement with the observation sheets and the check for understandings compared to the previous lessons, but it was only about 70% of students that could name the property and then the description consistently/properly. When student just give me the description, they are not telling me they know what property that goes with. Students need more* *practice in explaining this data.*

Majority of the lesson design required the students to design an experiment that required them to model/simulate soaking and then collecting data. Students had great practice with the data collection as they identified the necessary data needed to answer their testable question and then recorded before and after results. During the explain part of the lesson students were to compare data in two ways before/after and from group to group. Students got to modeling and simulation practices as they simulated soaking and assessed the models. We thought about the importance of this simulation as we compared it to what scientists have to do for quality control on materials. "

Researchers' Commentary

A careful examination of Brittany's science lesson plan and of her post-instruction reflection of it, presents a tale of high engagement cognitively and affectively with the CT policy driven innovation. It is clear that Brittany thinks of the innovation in a complex manner, that includes consideration of the purposes of science, how it should be thought of as a way of knowing, and how it should be taught. Furthermore, although it could be argued reasonably that her interpretation of CT systems thinking, in particular, was not fully expanded to include a quantitative consideration of the relationship between parts of a whole she appears to have genuinely attempted to integrate CT into this lesson and believes her lesson to be infusing data practices, modeling/simulation and systems thinking. Still, missing in her integration of CT in the lesson is evidence of integrating any of the CT practices in a way that would be clearly computationally relevant.

Summary of the PSTs Thoughts, Feelings, and Acts Concerning the CT NGSS Policy Driven Pedagogical Innovation

Overall, based on a holistic analysis of the other 37 participating PSTs' data (data sources: blog entry, pre-and post- CT drawings, lesson plan, post lesson plan reflection) and our detailed analysis of our two focal case studies we identified a number of prevalent PST key thoughts, feelings, and actions regarding the CT pedagogical innovation. First, the PSTs generally thought that the CT integration supported the implementation of what they understood as evidence-based, 21st Century science teaching practice. For example, in describing her drawing of her students engaged in CT while learning science, one PST stated, "*I intended to show… students working together with many different technologies… They use various CT skills to problem-solve, analyze data, program, etc. I also wanted to show students actually investigating themselves instead of sitting and watching*" (Delia, drawing activity). Second, PSTs thought that opportunities to engage in CT would benefit their students, particularly in the affective domain. They described CT as having the potential to make science to themselves and their learners as more fun, interesting, and engaging. They also described cognitive benefits, such as challenging students to think in new ways, as a positive outcome of the CT innovation. For example, the PSTs described CT and engaging in CT-related challenges as having benefits for students' learning specific science topics, including the positive values of teamwork and perseverance. Also, and consistent with the reform message underlying the CT module, most PSTs thought that opportunities for students to engage in CT while learning science could make science engagement more attractive to a wider range of learners, including those often underrepresented, including girls, second language learners, and people of color, and learners with special needs. This finding shows support by the PSTs when attempting to integrate CT in their science teaching to carry out the recommendations by Lee and Fradd (1998) to promote an equitable perspective in their teaching practices. Third, PSTs thought they would face a variety of challenges in their efforts to integrate CT into their science teaching. The challenges included lack of technology or funds to purchase technology (which some PSTs felt was necessary for CT integration), lack of time, and difficulty finding age-appropriate CT integration resources for elementary science aligned with their curricula. As one PST stated, "*my teacher gave me a curriculum, or a lesson plan straight from [county] curriculum that was like, "Do this." But then I didn't know where to add the computational thinking* (Susannah, post lesson reflection). While in our study we did not collect sufficient data to understand while some PSTs were able to overcome challenges of these sort and attempt to integrate CT in their lessons, we were left wondering if differences might be associated with their personal beliefs about science teaching or perhaps broader considerations of their mentor teachers' views of CT or perhaps the school culture.

Overall, the CT practices that the PSTs selected to integrate in their lesson ranged across the full spectrum presented in their CT module. See Table 3. A pattern we noted was that while many of the PSTs limited their selection to one CT practice (especially Data Collection and Models and Simulations) an appreciable number of the PSTs across the grades also attempted to integrate Computational Problem-Solving and Systems Thinking in their science lessons. Some of the PSTs felt that CT was particularly difficult to integrate into the elementary grades, and for those PSTs, they thought that only certain CT practices – data practices and to a lesser extent modeling – were developmentally appropriate to integrate into their science lessons. We speculate that these were the practices the PSTs were the most familiar with in science learning prior to their experience with the CT module (and likely most connected with lesson plans they were already implementing). Further research is called for to address this uncertainty.

Discussion and Implications

This exploratory study provides insight into PSTs' thoughts, feelings, and actions about CT integration as a reform effort in science education following in introduction to CT in their elementary science methods course. The use of the CAMCC model was of worth in this study, even though none of the members of our sample expressed avoidance of the policy driven innovation. Because the model combined cognitive and affective domains, it encouraged us to include, in particular, consideration of the affective domain, which we found informative. Where the model did not add meaningfully to our interpretive process was in providing us insight into any possible belief changes concerning the CT policy driven innovation based on the PSTs self-efficacy to integrate CT in their lesson plans. Our analysis of the data suggested a pattern of the PSTs becoming much more familiar with the surface features of CT, such as the names of the major practices. However, we were not able to discern to what level their self-efficacy may have been impacted. It may be that the "Visitors to CT Land" did not increase their self-efficacy of CT compared to those coded as "Good Citizens to CT Land" as result of the CT module, which possibly kept them from becoming "Good Citizens of CT land," but we saw no evidence of this interaction. In fact, in some instances we detected that some Good Citizens expressed high self-efficacy in how they decided to include CT in their lesson plans, but in those same instances such acts were also shallow or inaccurate based on our interpretation of CT.

Overall, the PSTs expressed a feeling of receptivity to the notion of the CT innovation, and thought of CT as potentially beneficial for their diverse elementary students to experience and learn. Introducing CT and CT integration through the use of robotics and citizen science appeared to contribute to participants' positive feelings toward the CT innovation. However, at times we noticed confusion among PSTs about the nature of CT (such as their view that CT r*equired* educational technology to present it to their students even though they were exposed in the CT module to the potential of using unplugged ideas for such integration), or about the relationship between CT and scientific inquiry. We also found that many of the PSTs thought that CT was a collection of discrete skills (e.g., graphing) that could be used while doing science, rather than a *different way of thinking* about science and the practices of science. This suggests that future iterations of the CT module – and teacher education efforts focusing on integrating CT across the curriculum - should support PSTs in developing a more robust understanding of how scientific inquiry and CT, two differing conceptual spaces, may be viewed by individuals as similar yet different but still able to be meaningfully connected. For example, traditionally science education has been portrayed as an inquiry guided process with a focus on problem solving involving the interpretation of empirical data. Computational thinking refers also to a way of thinking that is involved with problem solving (but its focus is on how the support of computational devices and what demands that places on use of data and data management and representation) so there is potential to make a meaningful connection between them in this regard. However, based on our experience in designing a CT module for PSTs and studying its implementation, we recognize that the challenge in integrating CT in a relatively short learning experience to achieve a sophisticated understanding (and that does not produce a shallow understanding as well as confusion) remains ambitious.

Because the module acknowledged that the PSTs were required to implement a reform that is not yet widespread or accepted in elementary science education, and the NGSS currently explicitly makes connections to CT in only two elementary standards, PSTs identified potential challenges they would likely face in implementing the educational reform. In particular, a significant number of PSTs expressed a hesitancy of implementing CT beyond their one course required lesson in their elementary science lessons if their classroom mentor teachers were not knowledgeable of CT or of its identified role as a core practice in the NGSS. They especially saw a limitation of teaching CT in the absence of educational technology even though in the CT module we explained how it could implemented in an "unplugged" manner without such tools.

A major practical implication we take from these findings is that PSTs, along with their mentor teachers, would benefit from additional discussions and field-tested examples about how to integrate CT in an unplugged manner or without the use of specialized educational technologies (beyond those readily accessible in their schools). Of particular value would be examples that are developmentally appropriate for elementary science lesson plans that integrate CT meaningfully.

We concur with the recommendation of Mouza et al. (2017) that future studies should continue to examine pedagogical innovations in including CT in teacher education. We would expand on such a recommendation to specifically include study of discipline-based pedagogy courses for educators, such as our present study of elementary science teacher preparation. These types of studies go beyond studying such innovations in computer and technology pedagogy courses that has been the norm. Currently, the integration of CT in science education remains severely under researched, and is imperative to undertake if the field is to advance by application of rigorous study informed by a theoretical framework and the collection and interpretation of empirical data.

Limitations

The sample size was a limitation of this study. Our 39 preservice **t**eachers came from one university in the Mid Atlantic, USA. The results might differ depending on the different type of sample conducting the same research at a different university or in differing classrooms. In addition, different instructors of the course could possibly impact findings based on instructor characteristics.

In addition, we did not account for the preservice teachers' background with computers. It may be that they varied more than we assumed, which we thought was limited. Their backgrounds of computers may have made a difference on their conceptions of computational thinking, but we did not include that information in our analysis.

Addendum

While our investigation focused primarily on documenting PSTs' intentions and avoidances of integrating science and CT, as result of our examination of the PSTs lesson plans in which the PSTs attempted integration of science and CT, we have some preliminary thoughts on the use of classroom lesson plans to search for points of integration between science and CT.

Akkerman and Bakker (2011) provide theoretical derived insights on how individuals may transverse differing sites or spaces by consideration of the concepts of *boundaries* and *boundary crossing*. As explained by Akkerman and Bakker, "A boundary can be seen as a sociocultural difference leading to discontinuity in action or interaction. Boundaries simultaneously suggest a sameness and continuity in the sense that within discontinuity two or more sites [spaces] are relevant to one another in a particular way (p. 133)." In the case of science and CT and to their possible connection in education across such sociocultural boundaries, it requires recognizing the different and similar features between the two spaces so that an individual may engage successfully in boundary crossing. Boundary crossing requires individuals to "search for ways to connect and mobilize themselves across social and cultural practices to avoid fragmentation" (Akkerman & Bakker, 2011, p. 133). The challenge is to create possibilities for participation and collaboration across a diversity of spaces, both within and across (Hermans & Hermans-Konopka, 2010, as cited in Akkerman & Bakker, 2011, p. 133). The aim of such boundary crossing is for individuals to make successful transitions and interactions across different boundary spaces. Evidence for such boundary crossing is examined in *boundary objects*, defined as artifacts doing the crossing by fulfilling a bridging function (Star, 1989, as cited in Akkerman & Bakker, 2011, p, 133). Therefore, based on this definition of artifacts, we believe in the area of elementary science teacher preparation that the lesson plan may be viewed as an artifact within the profession. Lesson plans offer teachers opportunity to both engage and show evidence of attempts at connecting or bridging functions across traditional recommended views of science education and computational thinking.

What we noticed in our own examination of our PSTs lesson plans was that the PSTs focused more on making convenient connections between science and CT without deep consideration of how such an integration would extend an understanding of 21st Century Science and its practices. Data collection was the most common practice that the PSTs pointed to when making a claim for the presence of CT in their science lesson plans, although Modeling and Simulations was a close second. In many cases, however, and perhaps because we did not emphasize it adequately in the CT module, data collection that could not be *quantified* (which is a prerequisite for it to be considered as such in CT) was presented by the PSTs as showing connection to CT in the science lessons. An example in the lower grades would be learners asked to identify and list the of color and textures of objects. A common CT practice referenced in science for older elementary students was the graphing of data. However, it was rare for PSTs to have their students use computational devices to graph the data using applications such as Excel. Also, in almost every mention of modeling being used to connect science and CT it was not accurately done by the PSTs. That is, the PSTs saw models as primarily physical models to represent phenomena, such as the globe for the planet and a fossil of a plant for the plant, rather than as quantitative models that could be used but use of CT to develop simulations. Beyond those two CT practices, we also noticed that oftentimes our PSTs confused a more colloquial or scientific definition of systems thinking (e.g., parts of a whole) as fulfilling the definition of a systems thinking in CT (i.e., which necessitates establishing a quantifiable relationship between components of a whole). In general, where our PSTs expressed that they saw many connections between science and CT it was in the shared use of linguistic terms, such as problem solving, data collection, models and simulations, and systems; however, the way they defined the terms was drawn primarily from science education and not from CT.

These findings both support and extend emerging research on teaching CT to PSTs that has identified some benefits (such as increased understanding of CT concepts, tools, and practices) but also major challenges (such as their developing a surface level of CT understanding and in developing misconceptions of CT), as reported in educational technology courses (Mouza et al. 2017) and in computer science education courses (Sadik, Leftwich, & Nadiruzamann, 2017). The encouraging finding from this study is that it suggests that PSTs are overall supportive of the CT pedagogical innovation and will not resist this particular innovation in teacher education. Therefore, efforts to integrate CT in their coursework, including in science methods, may be made and improved upon in an iterative process by reflection on practice without having to consider PST avoidance to this policy driven innovation. This is a major finding, since so many prior policy-driven innovations in education have faced educators' avoidance with resulting complications in enacting them. Much remains uncertain, however. Areas of uncertainty include the following key questions: How can PSTs come to understand what constitutes CT as defined by computer science? And, how do PSTs after CT instruction conceptualize CT and integrate it *meaningfully* and *accurately* into their lesson plans for young learners?

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Appendix A: Cheryl, A Focal Case of a "PST Visitor to CT Land"

Core Lesson Plan (Science)

PST's Name: X School: X

Grade/Subject:4th/Science

Mentor teacher: X

I. Purpose of the Lesson – ***What will the students learn in this lesson that you have planned?***

Next Generation Science Standard (NGSS) [Fill in number and description}:

4-ESS1- Identify evidence from patterns in rock formations and fossils in rock layers to support an explanation for changes in a landscape over time.

Disciplinary Core Idea (DCI) Full Description from NGSS and Code(s): **ESS1.C – The History of Planet Earth:** **Local, regional, and global patterns of rock formations reveal changes over time due to earth forces, such as earthquakes. The presence and location of certain fossil types indicate the order in which rock layers were formed.**

Core Practice(s): (must include at least one Computational Thinking Practice(s): **Constructing Explanations and Designing Solutions – Constructing explanations and designing solutions in 3–5 builds on K–2 experiences and progresses to the use of evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems. Identify the evidence that supports particular points in an explanation.**

Cross Cutting Practice(s) Description(s) and code(s):

Patterns: Similarities and differences in patterns can be used to sort, classify, and analyze simple rates of change for natural phenomena. (4-PS4-1)

Across the Curriculum Connection

What disciplines beyond science will you connect to in this lesson?

English Language Arts

What do you want your learners to learn about that discipline in this science lesson (beyond practice of previously learned skills or knowledge)?

I want my students to understand that they may use writing skills to express their findings about a scientific process. It is important that they know how to share their observations and conclusions in written form, as is done throughout the professional scientific community.

Assessment **(Note: Both formative and summative assessment are required for this lesson.)**

Formative: (*Some examples might be learner drawings of concepts, class assignments, Smart Board Clickers, learner responses in class discussions or responses to teacher question(s)).*

Students will respond to the following questions to assess understanding:

What is similar and different between yours and your partner's leaves?

Why are there differences?

What is similar and different about your leaf and the drawing you made?

Summative: Note: You must provide the assessment and the answer key as supplements to your lesson plan. (*Some examples include the end of the lesson Exit Cards, Selective Response quiz, or Brief Constructed Responses* (BCR).

Students will complete a BCR that answers the following question: If you did not have the original leaf, what would you be able to know about it from your drawing? What things would not be possible to know about the leaf?

II. Instructional Decision-Making – ***What knowledge of students influences my instructional decisions in this lesson? How will my instruction respond in order to remove barriers to learning and/or build on students' strengths?***

Knowledge of the Learners

As *based on your pre-assessment of your students' understanding of the concept you are teaching, and their backgrounds (including their developmental level, cultural, and special needs) what instructional decisions were made in your lesson planning?*

The students in my classroom are predominantly low-level learners. The students who are on grade level also struggle with complex tasks. The greatest challenge for my students is remaining on task because they become distracted easily. They have difficulty staying quiet for long periods of time. One of my students has a 504 plan for ADHD, and several others struggle to remain in their seats.

Usually, my students take a long time to perform tasks. I prepare lessons accordingly, and I make sure that I plan to give my class more time for a lesson than I would for a typical fourth grade class. I do not place too many demands on the students because I realize that they will not have enough time under conditions that require them to perform many tasks.

I have learned that the students need simple tasks and ample conversation time. I also realized that the students respond best to assessments that they may access on a computer. As a result of these factors, I selected appropriately simple activities and utilized Google Classroom.

Prior to this lesson, the students have begun learning about fossils. They did an online exploration provided by the textbook about dinosaur fossils as well as a lesson on how fossils form. However, they have yet to learn about patterns in fossil formation and patterns between fossils. I plan to cover these concepts in my lesson.

Instructional Materials:

Leaves

Paper

Pencils or colored pencils

Educational Technology:

Chrome books

Google Classroom

Management Considerations (Procedures, Transitions, Materials, Behavior)

Describe how you will coordinate and manage all procedures and transitions in your lesson.

This lesson involves several turn-and-talks. In order to get the students' attention between these conversations, I will use a technique that my students already know. In this technique, I say, "When I say stop, you say freeze. Stop. *Freeze.* Stop. *Freeze*." When I say this, the students know that I will be giving instructions. I use this technique often, so I know it is effective for classroom management.

Before students enter the classroom, I will tell them to keep their Chrome books closed. Normally, they open their Chrome books for a warm-up, but it is difficult to get every student off of the laptops once they are open.

I will also say the instructions for the leaves before I hand them out. Handing them out after instructions will allow my students to focus on me instead of the leaves. I will follow this technique for passing out the paper later in the lesson.

How do you plan to avoid and to react to possible student disruptions in your lesson?
I plan for several students to call out during the lesson, which will distract other students. I plan to call only on students who raise their hands. I will also remind the students who call out that I will respond to them when they raise their hands and wait to be called on. I think that this strategy will let other students who plan to call out as well know that it is inappropriate for the classroom setting.

I also foresee students asking for a different leaf. To avoid this possibility, I will announce that there will be no exchanging of leaves because each leaf has a unique story that we must appreciate. I think that making the students feel connected to the leaves will help them to accept the leaf they are given without many complaints.

III. Instructional Procedures – ***What instructional strategies and sequence will I use to ensure that every child is a successful learner in science education?***

Instructional Sequence:

Outli*ne a sequence for the experience including your actions, the learner, actions, purposeful questions you intend to pose, and clear directions for any tasks or activities. You must demonstrate indirect instruction and/or student-centered strategies. Consider how you will apply authentic conditions to the learning experience.*

DO NOT SCRIPT YOUR EXACT WORDS THAT YOU WILL USE WHEN YOU CONDUCT THE LESSSON EXCEPT FOR ANY PURPOSEFUL QUESTIONS YOU PLAN TO ASK.

Instructional Sequence (USE THE 5E Model)	**Approximate Time**	Procedure (Include purposeful questions)
Engage	5 minutes	Ask students, “What do we already know about fossils?” Call on about five students to respond to this question. Tell students that today they will be making their own fossils. They will be using their fossils to learn more about how fossils can tell us about life in the past.

Explore	20 minutes	Hand out a leaf to every student. After handing students the leaves, provide them with five minutes of think time to make observations. Next, ask students to compare and contrast their leaves with a partner's. Ask, "What do you notice is similar about yours and your partner's leaf? What is different?" Encourage students to think about why their leaves may have these differences. Give them examples to scaffold their learning. Say, "For example, did one leaf get more sunlight than another? Did one leave fall of the tree sooner than the other?" Give students at least 5 minutes to discuss with their partners. Circulate around the room to make sure that students are on task. Bring the conversation back to whole-group discussion when the students seem like they are finished discussing the differences and similarities. Ask the pairs to share with the class some of the similarities and differences they noticed. Repeat back to the class what each pair observed so that there are no repeats of shared observations. When a pair shares what they found to be different between the leaves, ask, "What do you think is responsible for this difference? Why are they different?"

Extend/Enrich	30 minutes	Explain to students that they will now create their own fossils. First, show students how they will create these fossils. We will model the process using the materials we have. The ground will be the desk, the paper will be a layer of mud, and the pencil will be the sediment that builds up over time and hardens into rock. After modeling, allow the students to create fossils of their own. Each student should have out a pencil or colored pencil. Pass out the pieces of paper. Supervise students working on their fossils. Make sure that each student's drawing shows the imprint of the leaf. When students are done creating their fossils, tell them to turn and talk to a partner about what is similar and different between their own leaf and their drawing. Have students share their findings with the whole class.
Evaluate Formative Summative	20 minutes	Formative: Ask students, "How are the fossils you created similar to those of dinosaurs? What are things we might discover about dinosaurs from looking at fossils? What are things we might never know about dinosaurs from looking at fossils?" Have a whole-group discussion about these findings and answer any questions they have about fossils. Summative: On Google classroom, pose the following question: If you did not have the original leaf, what would you be able to know about it from your drawing? What things would not be possible to know about the leaf? In the directions, tell students they must answer both questions with their original ideas in order to receive full credit. They must also respond in at least four complete sentences. Differentiation: ESOL: N/A

Differentiation *How are you differentiating your assessment, as appropriate, for learners who are?* *ESOL:* *With Exceptionalities:*		With Exceptionalities: I have three students with autism in my class. In addition to the fossils that they create, I will also have premade ones for them to use in order to answer the questions. I will also give these students the opportunity to respond orally to me so that I can help scaffold their responses.

Appendix B: Brittany, A Focal Case of a "PST Good Citizen in CT Land"

Core Science Assignment

PST's Name: x__________________________**School:** X

Grade/Subject: 3rd Grade/Science

Mentor teacher: X

I. Purpose of the Lesson – *What will the students learn in this lesson that you have planned?*

Objective: We will plan and conduct an investigation about liquids by using the process of soaking. We will produce data that will answer a testable question about the physical properties of a pretzel.

Students will continue learning about the physical properties and how they can be changed by processes. Students will be recording data that identifies both the physical property and its description in order to reflect their difference; nouns are properties and adjectives are describe the property (across the curriculum connection).

Prep:

1. *Beakers of solutions*
2. *One paper per group - have group names, location, and solution written on papers.*

Next Generation Science Standard (NGSS)

Disciplinary Core Idea (DCI) Full Description from NGSS and Code(s):

PS1A: Structure and Properties of Matter

2-PS1-1 Matter and Its Interactions

Core Practice(s): (must include at least one Computational Thinking Practice(s):

2-PS1-1. Plan and conduct an investigation to describe and classify different kinds of materials by their observable properties. [Clarification Statement: Observations could include color, texture, hardness, and flexibility. Patterns could include the similar properties that different materials share.]

CT Ideas:

Data Practices - Recording / Analyzing Observables Properties - Students will carry out a design to examine what physical properties are and what processes alter physical properties.

Modeling & Simulation Practices - Modeling the process of soaking to understand observable properties.

System Thinking Practices - Understanding (the system of) observable physical properties and how they can change as a process is performed on them.

Cross Cutting Practice(s) Description(s) and code(s):

Patterns

(2-PS1-1) Patterns in the natural and human designed world can be observed.

Cause and Effect

(2-PS1-4) Events have causes that generate observable patterns. → These events would be the process of soaking.

(2-PS1-2) Simple tests can be designed to gather evidence to support or refute student ideas about causes. → We are testing to gather evidence.

Across the Curriculum Connection

What disciplines beyond science will you connect to in this lesson?

Writing

Reading

What do you want your learners to learn about that discipline in this science lesson (beyond practice of previously learned skills or knowledge)?

Writing:

-Understanding the difference between nouns and adjectives.

-Developing complete conclusion sentences.

Reading:

-Using information to make inferences.

Assessment (Note: Both formative and summative assessment are required for this lesson.)

Formative: (*Some examples might be learner drawings of concepts, class assignments, Smart Board Clickers, learner responses in class discussions or responses to teacher question(s)).*

-Recording Sheet for observation - students are producing their testable question and recording their before and after results here. Students will demonstrate their understanding of physical properties here through group work and discussion time.

Summative: Note: You must provide the assessment and the answer key as supplements to your lesson plan. (*Some examples include the end of the lesson Exit Cards, Selective Response quiz, or Brief Constructed Responses* (BCR).

-Check for Understanding Worksheet - At an independent level students are demonstrating if they can explain how processes affect physical properties by identifying and describing physical properties.

II. Instructional Decision-Making – *What knowledge of students influences my instructional decisions in this lesson? How will my instruction respond in order to remove barriers to learning and/or build on students' strengths?*

Knowledge of the Learners

As *based on your pre-assessment of your students' understanding of the concept you are teaching, and their backgrounds (including their developmental level, cultural, and special needs) what instructional decisions were made in your lesson planning?*

-Considerations from Pre-assessment - Focus on identifying the property AND the description.

-Accommodations Sped

-ELL Grouping

-Considerations about behavior for grouping

-Sentence Starters for Hypothesis and Conclusion

Pre-Assessment Questions

1. What are observable physical properties? Can you give me examples?
2. How do physical properties change?
3. What processes can we use to change physical properties?

4. What type of observable properties can we change with experiments?

Instructional Materials:

Flipchart

Observation Sheet

Check for understanding

Cups for liquids (8)

Pretzels (two for each group)

Laundry Soap

Rubbing Alcohol

Vinegar

Warm Water

Oil

Orange Juice

Mouthwash

Educational Technology:

Smart Boards

Timer on board

Management Considerations (Procedures, Transitions, Materials, Behavior)

Describe how you will coordinate and manage all procedures and transitions in your lesson.

- *Materials ready at their desk - students come right to carpet in beginning of lesson*
- *Teach controls timer on the board*
- *Jobs - recorders get to observe first. Recorders this session are the group members that didn't get to do it for the last investigation.*

- *Warning about how much time is left for observations.*

How do you plan to avoid and to react to possible student disruptions in your lesson?

- *Talk about safety - Do not eat*
- *For time and management of materials students will receive twin pretzels. Ms. Vila will start the soaking process for them for time (also to avoid spills on the floor) with one pretzel and then they will receive another identical pretzel to do the before process observations.*
- *Limited materials in front of them - one soak in one solution.*
- *Plan recorders - everyone is a recorder over the course of the unit.*
- *Check ins - (whole class) at this point your group should have two properties written down*
- *Circulation*
- *Observation Team - if students cannot handle the materials well*
- *Grouping - IEPs / behavior*

III. Instructional Procedures – *What instructional strategies and sequence will I use to ensure that every child is a successful learner in science education?*

NGSS Standards

[School District's] Curriculum → Because of mentor's experience we changed the object from chalk to a pretzel

- Both of these were used for considerations of what topic to explore and what parts to focus on. They also both encourage the lesson design as they call for students to inquire and design their own investigations.

Instructional Sequence:

Outli*ne a sequence for the experience including your actions, the learner, actions, purposeful questions you intend to pose, and clear directions for any tasks or activities. You must demonstrate indirect instruction and/or student-centered strategies. Consider how you will apply authentic conditions to the learning experience.*

Instructional Sequence (USE THE 5E Model)	**Approximate Time**	**Procedure** (Include purposeful questions)

Engage Start at carpet.	About 7 minutes	The teacher will say something like, "We have done a lot with observable properties and using processes to make them change. What are some processes that we have done already?" *student answers* What type of properties did it change? What were the descriptions of the properties? Is green a property? Is bigger a property or does it describe a property? Read Slide 2 - Introduce our speaker, an Ethiopian American female chemist who uses observable properties at her work -have students think about different processes that could affect a pretzel. If they don't bring up soaking ask what happens when they put their cereal in milk for too long? Read objective. Today you will be designing the experiment! The teacher will say something like: "I recently saw some pictures on the news that reminded her of our science lessons. Can you think about what was happening in these pictures? What was causing change to these buildings and what was being changed? *Turn and Talk*" *student answers* The teacher will say something like: "Recently we have heard a lot about hurricanes on the news and how they have harmed many homes. Hurricanes bring a lot of rain that creates flooding, like you can see in these pictures. Scientists and engineers have to perform a lot of tests on materials to make sure they can withstand certain processes. In these pictures things are being soaked in water. We can see that the water is causing a lot of damage to the homes. Let's investigate soaking ourselves and observe what properties can be changed by materials

		soaking in different solutions.”
Explore 7 Groups with about 3-4 people - Premade groups with location and material they will use. One paper per group - have group names, location, and solution written on papers.	About 20 First 5 minutes at carpet Soak for 5 minutes Students will need about 5-7 minutes to observe and record.	**Read first speech bubble.** Our speaker is reminding us what we need to do to design our experiment for the process of soaking. In your groups, you will need to come up with this on your own. **Read rest of slide** <u>Refer to their designing the experiment paper:</u> Have students recall what was the procedure from our other tests? Two items. One uses the process and the other one is for observation. Remind them the difference between the variable and the control variable. → Write under the speech bubbles for them. Mention descriptors are not properties. Descriptors are the adjectives that define our properties. Properties are nouns. Go through a few examples. Write on board as a reference. Expectation is to write both on their papers. Model the example - Ms. Vila did the experiment last night with room temperature water. In order to get through our experiment, what do you think group expectations will be? Call students off the carpet by their groups. Give them group paper and the recorder assignments. Teacher checks investigation design paper and gives

		them the before process pretzel. Teacher begins soaking at her desk for all the groups, announces it has begun and puts timer on board. After timer teacher pulls out all pretzels. -Take pictures of the results so students can refer to picture on day 2 - Students that have completed their data collection (observations) may get their group's soaked pretzel. As teacher circulates look at papers to make sure they identified the property and the descriptor when recording the observations. As students finish they may observe other groups. Ask them about their predictions and findings to their testable question → expectation, time to just stop and chat? Observations must be written as property-description.
Explain - Day 2	15 minutes	Groups share their experiment findings. - Post pictures in slides Make sure students state the process/solution used in their test, what observable property changed and its descriptions. Ask if all groups had this finding? What was true with all soaking? What was special about certain solutions? What was no change? *Teacher records briefly* Why do we see differences is our data? What is changing each time? Note: reasons for differences in soaking is not really the process since the all are doing the same process...it's the differences in liquids "What are some big ideas about properties? How

Closure		would we define it? How are they changed?" Turn and Talk / Discuss and create a class definition of properties. "Now let's think like scientists and engineers. If you wanted something to last for a long time, would you make it out of pretzels? Why not? Why is it important that use scientists and engineers investigate the process of soaking? Why is it important to investigate the observational properties – helps us describe objects and identify change. Why don't all materials change so easily? *What doesn't change so easily that you might want to use instead?* Give out Check for Understanding Read through once on carpet ask for questions. Read to them at their desk - students fill out as I read to them.
Extend/Enrich If time for Day 2		Scientists use observable properties to help create effective solutions to problems that we have in the community. Scientists test materials for buildings to make sure they are safe. They also have to do this for food! One big problem that we have in the world is having enough food. Scientists have been experimenting on food to see how we can make our food last longer. Show picture of the apples. Ask: (take student answers) -Which one do you want? -What observable properties make you think that?

		Turn and Talk -Let's think as scientists what test can we do that might help us determine a way to keep this apple from getting rotten so fast? What processes should we investigate? Use what you know about keeping food fresh to support your answer.
Evaluate Formative		Formative During the Explore / Explain piece Design/Observation sheet - as a group are students able to fill this out properly. Observations on discussions - during observation time and explain Note: The two students in the class with IEPs will not be expected to record, but they will have a chance to observe first just like everyone else. They will be in groups where someone will help him contribute to the procedure. For the explain portion: they will be asked to read the question and report first orally on their findings. If time accelerated students can do the extension during day 1. No ESOL learners are in this classroom. Check for Understanding – after discussion At their desks students are to independently fill out this worksheet. IEP students will have to do this individually with the PST or her mentor teacher, so it can be read to them (and receive help with comprehension, attention, and formatting). IEP Students:

Summative Differentiation: *How are you differentiating your assessment, as appropriate, for learners who are?* *ESOL: none*		1) Heterogeneous Grouping 2) Will not be required to fill out their own observation sheet. 3) Teachers will read Check for Understanding questions to students. Help to manage attention. 4) Teachers may write for students. 5) Periodic check ins during the investigation to clarify thinking and engage in science thinking behind investigation...not just fun High Students: ● Help with the low students. ● May start to read and answer the apple question before discussion / closure (day 1 if time). quality control on materials.