Actions and Approaches of Teachers Communicating Computational Thinking and Engineering Design to First Grade Students (RTP)

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Introduction

As engineering design and computational thinking (CT) concepts are included in classrooms, veteran teachers have to develop new pedagogical content knowledge for these unfamiliar topics as elementary teachers often have little background or preparation in these areas [1], [2]. There are a number of professional development (PD) programs targeting engineering [2], [3], however research in this area often examines what teachers can and will do when integrating engineering and CT into their classroom practice in the semester or year following the PD [2]. While it is important to continue to develop our understanding of teachers actions and practices as they are implementing engineering and CT in their classrooms, there is also a need for a more longitudinal approach in looking at how to support teachers with continued implementation in the classroom. Within the research on teacher PD and teacher change, a number of factors have been found to result in changes in teacher practice. These include the use of a workshop model, engaging in active learning, focusing on specific subject-related content or pedagogical practices, and a need for teachers to have sustained support after returning to the classroom [4], [5].

In this study, we are interested in the practices of three early elementary teachers as they implement the same engineering and CT instruction in their classroom across two years. The following research question guided this work: If and how do first grade teachers’ classroom actions change as they gain experience with teaching engineering and CT?

Literature review

With the increasing attention being placed on integrated STEM instruction [6] and with the integration of engineering and computational thinking (CT) into K-12 science instruction [7], recommendations are being made for teachers to integrate content, pedagogy, and thinking skills from these two areas into their classrooms. CT and engineering have been linked as [8] defines CT as an overlap between mathematical and engineering thinking. Additionally, within the 2011 NRC report from the Workshop on Computational Thinking, it was noted that CT is crucial to the development of engineering habits of mind and in solving engineering problems [9]. Therefore, given the cross-disciplinary nature of CT and engineering and the reality for teachers to address current educational reforms, both CT and engineering provide avenues for thinking about STEM integration and the successful integration of both engineering and CT into classrooms [10], [11].

Within the work on elementary engineering instruction, research has found that when learning engineering, students need opportunities to learn from failure, work in teams, practice all phases of the engineering design process, and apply their mathematics and science knowledge, among others [12], [6]. Similarly, in CT, students need opportunities to practice CT competencies in a variety of developmentally appropriate problem contexts [11]. Teachers can support their students in these endeavors using an array of pedagogical techniques. For example,
research has found that students often model their discourse and behavior off their teachers [13], [14]. Therefore, teachers can model effective engineering practice with their discourse and actions. Research has also found that teacher questioning is an important avenue to prompt students to think deeply about problems and make connections to their other knowledge [15].

Barriers to teaching engineering and CT

However, with engineering and CT integration becoming more common in the elementary classroom, this also presents a number of challenges. Elementary school teachers do not have as much background in STEM subjects as in others, such as literacy. While this trend is changing, engineering content and practices are often not required or taken within elementary teacher education [1], [16] and few teacher preparation programs offer courses in CT [2]. Furthermore, elementary teachers have limited instructional time for science with or without engineering and CT, limited access to materials in this area, and limited opportunities for professional development (PD) [1], [10]. This poses a struggle for teachers to not only teach STEM subjects at the same level as more familiar ones, but also to integrate new content into these areas [10]. For example, Newton and Newton found that when teaching science “teachers with less [science] content knowledge in their educational background tended to interact less, to ask fewer questions overall, and fewer questions about causes in particular” [17, pp. 373].

Additionally, research has found that even with PD, the integration of high-quality engineering into classroom instruction is difficult [12], [18], [19]. In engineering design, [3] notes that in the first year of engineering implementation, classroom teachers were focused on overcoming their fear of engineering and [20] found that many teachers new to engineering were implementing lessons there were replications of what was done in the PD program. A similar story is seen with CT. The integration of CT requires teachers to have a deep understanding of their own discipline as well as the knowledge for how CT concepts relate to what students are learning in the classroom [11]. Additionally, in CT these understandings are often incomplete or focused on the more “high tech” versions of computational thinking and STEM. This suggests that even with engineering and CT becoming more commonplace and with the field is developing a better understanding of what this integration could look like, more work needs to be done. We need to better understand how to prepare and support teachers in order to see the types of practices and implementation that is suggested in national documents and standards [7].

Overcoming the barriers to teaching engineering and CT

One of the most common approaches to helping teachers overcome some of these barriers to implementation is through professional development that is targeted at both the preservice and inservice levels [2], [10], [21]. These professional development programs are often designed to develop teacher content and pedagogical knowledge, increase efficacy in and attitudes towards the subject, improve classroom practice, and foster student learning [22], [23]. Many of these professional development programs have seen success with both beginning and experienced teachers [10], [24], [25]. For example, [2] found that preservice teachers who participated in
computational thinking modules in their teacher education programs were more likely to report that computational thinking is central to learning in many disciplines, such as art and English in addition to computer science and mathematics. Also, that computational thinking did not necessarily involve the use of computers, but also included concepts such as pattern identification and sorting. Within engineering, professional development programs have been shown to increase teachers’ confidence, efficacy, and attitudes towards teaching STEM subjects which can lead to better teaching of these subjects [15]. Even though it is important to continue to examine how to better support and prepare elementary teachers to overcome some of the barriers to implementation, another important piece of this puzzle is to look at what happens after the PD as teachers are bringing this novel content and practices back to their classrooms [25].

Research Design

This study utilized a multiple case study design as suggested by Yin [26] to understand how three first grade teachers were integrating engineering and CT into their classroom instruction as they implemented the same engineering and CT curriculum across two years. A multiple case study design was chosen as it allowed an in-depth investigation within and across a similar real-world context to better understand how or why certain actions occurred related to the phenomena under investigation [26]. These cases were bounded by participation in the larger NSF-funded project across two years, which included participation in the related PD offered as part of the project and teaching the first grade curriculum unit in their classroom. The unit of analysis for each of the cases was the teachers and their classrooms located within a small Midwestern public school district during implementation of the same integrated STEM+C curriculum unit.

Context and Participants

In this particular study, we analyzed data from the classrooms of three first grade teachers, Miriam, Moria, and Shannon (pseudonyms), over the course of two school years. They taught at the same K-5 public, Title I elementary school in a small midwestern city. The student demographics for this elementary school consisted of 1% Asian, 16% Black, 38% Hispanic, 36% White, and 7% two or more races and 73% of the students were eligible for free or reduced-price lunch. At the beginning of the study, Miriam had eight years of teaching experience, Moria had one, and Shannon had 10.

Each of these teachers were part of a larger, externally funded project focused on the integration of STEM and CT for early elementary students in both in-school and out-of-school environments. As part of this larger project, the teachers participated in a series of activities to support their STEM teaching across the two year. In the first year, the teachers participated in a summer professional development (PD) program hosted at a partner university near their school. This professional development program was developed by the authors and in collaboration with other researchers who were part of the larger project to teach K-2 teachers about integrating
STEM and CT into their classrooms. Specifically, the teachers learned about the PictureSTEM curriculum, which was developed by the authors and others to integrate STEM with literacy in grades K-2. The curriculum is described in the following paragraph. Following the PD the teachers were given the supplies needed to implement the curriculum. During the school year, the teachers worked closely with each other before and during implementation to help each other with understanding of the curriculum and how it would be implemented, planning for and designing classroom management strategies, and to offer other support as needed. During the following summer, in their second year, the teachers continued to work with the partner university and researchers to further develop their understandings of integrating engineering and CT into their classrooms. They implemented the same curriculum unit in their classrooms during the subsequent school year, again having the support of their colleagues and the researchers. During both years of implementation, the researchers observed the class each day to collect data and support the teachers as needed. In addition to the three teachers studied in this paper, there were two other first grade teachers from the same school who were part of the larger study and implementing the curriculum at the same time, but excluded from this study as one teacher did not follow the curriculum closely and the other did not participate in both years of data collection.

Curriculum Description

This study involved the first grade unit, Designing Hamster Habitats, from an integrated literacy and STEM+C curricula called PICTURESTEM, that is part of the larger project mentioned above. Within this curriculum, there are five main components of the curriculum that include: 1) engineering design as the interdisciplinary glue, 2) engineering design to provide opportunities for student participation in problem scoping as well as solution development, 3) realistic engineering contexts to promote student engagement, 4) high-quality literature to facilitate meaningful connections, and 5) instruction of specific STEM+C content within an integrated approach. Across both years, all three teachers were asked to implement the first grade unit in their classrooms. This unit consisted of an introductory lesson and six pairs of literacy and integrated STEM+C lessons centered around designing a new pet habitat for the clients of a fictional pet store, Perri’s Pet Palace. More specifically, students learn about animals’ basic needs, how habitats provide for these needs and explore characteristics of two- and three-dimensional shapes before designing an exercise trail for a hamster habitat.

Data Collection and Analysis

The data consisted of video recordings from each classroom for each of the lessons throughout the unit across both years of implementation and audio recordings of the debrief interviews with teachers at the end of the unit for both years. Additionally, field notes and images taken by researchers in the classroom during implementation were available for reference as needed. To gather the video recording data, one video camera was focused on the teacher for the entire time that the curriculum was implemented. Additionally, there was one video camera
focused on student groups for the times that the students were working in small groups or independently. During year one, the debrief interview was conducted as a group interview with all teachers present and during year two the interviews were conducted one-on-one with a teacher and a researcher. Although the questions were the same in both interviews, in the year two interviews, many of the follow-up questions were focused on changes from year one to year two. The primary data sources utilized in this study consisted of the videos focused on the teacher as well as debrief interview audio recordings from year one and two. These classrooms videos were initially analyzed following completion of year two by a researcher and one of the first grade teachers who had participated in the study. The analysis employed an open coding method that was focused on identifying and comparing teacher actions, particularly those within the engineering and computational thinking instruction. Using the initial codes generated from that open coding method from the initial viewing of the videos, the researchers watched all of the videos for a second time and focused on those observations around each of the codes by keeping detailed notes and organizing examples from those data. These excerpts were categorized into larger themes based on the changes observed between year one and year two of implementation across all classrooms. These themes are described in our results section.

Limitations to the Study

In this study, we focused on three different teachers at the same school. This allowed for us to analyze the actions of each of these teachers in depth while also reducing the effects of possible differences that can exist when looking across multiple schools. However, this multiple case study approach is not generalizable to all cases as it was only three teachers at the same school and who participated in the larger project. Additionally, we only collected data over the course of two years. Therefore, while this is a start at examining continued implementation, we cannot make claims about the longer term effects on the teachers’ practice. We also cannot make strong claims about why the teachers acted in the ways that they did as the data collection was focused on participant observation. Although the debrief interviews gave us some insight into the teachers’ thinking about their teaching, the interviews were not focused on this specific study, rather on the curriculum and the larger project more generally.

Results

We observed several changes in the teachers’ actions from their first year to their second year of curriculum implementation when looking at their engineering and CT instruction. These changes fell into six larger themes. These themes are grounding within the engineering design challenge, use and descriptions of computational thinking, increase in connections, emphasizing teamwork and failure, changes in questioning, and making it their own. In this section, we describe each theme along with examples of how the teachers changed from year one to year two.
Grounding within the Design Challenge

When examining aspects of engineering design across the lessons and over the two years, there was evidence that the teachers summarized and discussed the design challenge much more often and intentionally in the second year. They did this by 1) providing multiple examples of problems that can be solved through engineering design instead of just the problem they would be solving in this challenge and 2) connecting the activities the students would be doing in each of the lessons to the engineering design challenge. In year one, all three teachers related the playground at the school, which the students used every day, to the hamster exercise trail design challenge and related criteria. In this example, Miriam introduces the design challenge, comparing the given problem requirements to the students’ playground.

Miriam: Why did she say we need bigger hamster cages?
Cory: Um...so more hamsters can fit?
Miriam: Okay did she say “I have so many hamsters I don’t know what to do with them”?
Class: No.
Miriam: No, she wants the hamsters to be what? [waits for student response] She wants the hamsters to be what? Zoe.
Zoe: Happy and healthy.
Miriam: Happy and healthy. Happy, healthy hamsters. [...] Now would you be happy healthy children if our playground had one swing?
Class: No.
Miriam: No. Would you be happy healthy children if I said you can all have recess in first grade on this rug?
Class: No.
Miriam: No. Would you be happy healthy children if I said you can all have recess in first grade on this rug?
Class: No.
Miriam: And jammed all of you in there?
Class: No.
Miriam: No. So what Perri is trying to do is get help making hamster cages bigger and she wants her hamsters to be happy and healthy. They’re already in a cage, if we’re going to keep them in a cage we want to make sure that they’re happy, healthy and maybe having… [waits for student response]
Class: Fun.
Miriam: Some fun. That’s why you said you go on that stuff to have fun. Is
it fun to sit in a box all day?

Class No.

Miriam Okay, so we need to help Perri.

As seen in the representative example above, they used this metaphor to discuss and help students understand one of the criteria given by the client, that the hamster habitat needed to be fun and exciting for the hamster. All three teachers related these criteria with the playground example, specifically asking students if they would have fun on a playground with no slide, swings, or structures to climb on.

However, in year two, this comparison of the playground to hamster exercise trail was still used in relation to the design challenge, but the teachers also all added other applicable examples when explaining engineering design and the types of problems that can be solved using engineering to their students. For instance, Miriam used a school backpack program to explain that there are problems to be solved every day in students’ own lives and Moira used a problem scenario of people with wheelchairs getting into their car. Shannon also used a backpack example in year two, but it was slightly different from Miriam’s as it was focused on what if the backpacks were too heavy for students. In the following example, Shannon first reminds students how much they take home in their backpacks on specific days of the week and then asks for helping in solving the problem of what if the backpacks are too heavy for students.

<table>
<thead>
<tr>
<th>Shannon</th>
<th>Let’s think about a problem that you might have. On Thursdays what goes home in your backpack? What goes home Diane?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diane</td>
<td>Um...book?</td>
</tr>
<tr>
<td>Shannon</td>
<td>Your reading book. What else Alison?</td>
</tr>
<tr>
<td>Alison</td>
<td>Your binder.</td>
</tr>
<tr>
<td>Shannon</td>
<td>Your binder. What else Ethan?</td>
</tr>
<tr>
<td>Ethan</td>
<td>Homework.</td>
</tr>
<tr>
<td>Shannon</td>
<td>Your homework. Jordan?</td>
</tr>
<tr>
<td>Jordan</td>
<td>Monday folder?</td>
</tr>
<tr>
<td>Shannon</td>
<td>That goes home on Mondays but on Thursdays our backpack is especially heavy because your reading book also comes home on Thursdays. Right? So what do you think could help you carry around that heavy backpack. [...] What kind of bags have you seen that help you carry those heavy backpacks. Alison?</td>
</tr>
</tbody>
</table>
Alison: Other people’s backpacks.

Shannon: Other people’s backpacks. Okay so what have some of those backpacks had on them that might make them easier to carry?

Alison: The straps?

Shannon: Okay what kind of straps?

Alison: (indistinguishable)

Shannon: Okay so maybe wider straps. What else?

Student: Handles.

Shannon: Handles on the backpack. Good. What else Connor?

Connor: [...] a food backpack.

Shannon: Okay so what could go on that food backpack to make it easier to carry?

Connor: Probably dinosaurs.

Shannon: Dinosaurs? Dinosaurs could go on the food backpack to make it easier to carry? Alright well that’s a new one. You know what I was thinking about, wheels. Wheels, right? Have you seen backpacks that have wheels on them?

Class: Yes!

Shannon: Yeah that roll. Okay so, an engineer looked at the problem of heavy backpacks and kids. Heavy backpacks, hard for kids to carry so someone came up with the idea to put wheels on backpacks. Then instead of carrying that heavy backpack around on your back, you can roll it.

As seen with this example and when looking across the examples used by the teachers in year two, all three of them provided additional design examples to students in the introductory lessons beyond the specific challenge for the unit. In addition to presenting more examples of engineering design, the ways in which the teachers connected to the design challenge were different in year two. The teachers were seen making more frequent connections to the overarching design challenge throughout the lessons, and their references were more focused how that lesson or activity would help with the design challenge. In year one, the teachers quickly revisited the design challenge at the beginning and end of each lesson according to what was written in the curriculum. In this example Shannon reviews the design challenge with her students.
Shannon: Yesterday we got an email from who?

Class: Perri!

Shannon: Perri. And Perri is the owner of a pet store and Perri had a problem. What was Perri’s problem, Tim?

Tim: She needed to stretch out and make the hamster’s cages bigger.

Shannon: Absolutely, so Perri’s problem was she needed some bigger cages, more room for her hamster to have some exercise.

However, in year two the teachers went a step further by incorporating and revisiting the design challenge, criteria, and the engineering design process throughout the lessons and not just as a quick review at the beginning of the lesson. For example, throughout each lesson, Miriam was seen asking her students why the activity they were working on was important and then would bring it back to the design challenge. As part of this she also explained how each activity could help her students fulfill the design requirements.

Miriam: Why did we spend two days talking about hamsters and habitats, Sydney?

Sydney: Because um we want to know um how um we want to build our hamster habitats.

Miriam: Okay we’re going to be building a hamster habitat for who? Who are we working for, Arnold?

Arnold: Perri!

Miriam: Perri, and Perri is our what?

Class: Client!

Miriam: Alright so we’re talking about these keywords. Perri is our client and she needs us to help us expand her hamster cages by adding an exercise trail and that will make our hamsters happy and healthy. So we did the science part [...] on lessons 1A, 1B, 2A, 2B. Lesson 3A and 3B are going to be switching to math. In order to build these habitats, you’re going to need to know some things about shapes. What’s the fancy word for learning about shapes? We talked about this when we learned about shapes. What’s that word, Kathleen?

Kathleen: Geometry.

Miriam: Geometry. So today we’re going to be talking about geometry as
we review shapes and then we’re going to be learning about what shapes can do. So we are switching a little bit from the science to the math.

In another classroom and in the example below, at the end of the CT lesson on algorithm design, Moira is discussing with her students what makes a good algorithm.

Moira What makes a good algorithm? When they all look the same, what makes it good though, Jamie?

Jamie Um, they give us good, good detailed instructions so that it will all look the same and it will look really pretty.

Moira Nice!

Jamie (Indistinguishable)

Moira Exactly Jamie. Jamie is absolutely right. The more detailed you are, the better your algorithm. Because when we’re making our algorithms, if somebody wants to try it, we want it to look all exactly the… (waits for student response)

Class Same.

Moira (Later in the lesson) What did we just build? What’s that big juicy word? It’s called a what […] Sam?

Sam “Alagrimth!”

Moira Algorithm. What’s it called everybody?

Class Algorithm!

Moira Okay, so we just made an algorithm. When we design our hamster habitat cages it’s gonna be like an algorithm. Steps for them to follow to build it.

As seen in this example, Moira was not only bringing closure to the CT lesson that they just completed on algorithms, but she also took the opportunity to relate this learning back to the final design challenge. This type of connection between the engineering design challenge and what the students learned in individual lessons was much more common across the three classrooms in the second year.

Use and Description of Computational Thinking

The primary computational thinking elements emphasized in the curriculum were centered around sequencing, algorithms, debugging, and sorting. Despite including elements of
CT within the curriculum unit and covering CT as a focus in the summer workshop, the explicit use of CT terms and explanations around the various CT competencies were used sparingly during year one. A more common alternative, was that the teachers were observed using synonyms or discussing only parts of a CT element with their students during CT-focused instruction. For example, in the transcript below from year one, Miriam is walking students through the design process and emphasizing what they can do if their designed solution doesn’t work.

Miriam: After we try it and test it, then we’re going to have to see if it…

Class: Works.

Miriam: Works. And if it doesn’t work what do we do? We have to…

Student: Start over.

Miriam: Do we always have to say ‘oh this didn’t work’ and get rid of the whole thing?

Class: No!

Miriam: No, maybe there’s just one little part that we need to fix.

Within this transcript the teacher is implicitly getting at CT ideas of debugging and troubleshooting that are highlighted in the curriculum as she describes how sometimes within redesigning you might be able to identify and fix one little part of their design instead of starting over. However, as seen within this example and more commonly across year one, the teachers did not explicitly label this idea of looking for one little part to fix or identifying possible errors as troubleshooting or debugging. In the second year, the teachers were observed more frequently using the explicit CT terms in their classrooms and across multiple the lessons with their students. This example shows the beginning of a lesson where Miriam is helping students to make connections from this lesson to the bigger lesson, while also introducing explicit CT vocabulary.

Miriam: Alright so the word for today is…(waits for student response)

Class: Algorithm.

Miriam: Algorithm. An algorithm is a specific set of directions like what you just wrote, that tells us how to build something. In our case, we’re going to be telling Perri how to build and then run our exercise trails for our hamsters. When we’re following the algorithm it’s going to be very important for us to get the same
results sometimes and maybe not exactly sometimes but similar. [...] make a model of your exercise trail for Perri and then explain to her how to use it. And the way we explain it is by writing an algorithm. [...] We need to know how to write and give directions.

In this year two example, Miriam is seen not only introducing students to a definition for algorithm but also helping students to see why this is important for the students to know and how that word applies to the bigger engineering design challenge. In addition to explicitly using the CT vocabulary in their classrooms, the teachers in year two were also seen more intentionally making connections to bigger CT ideas like sequencing, efficiency, identifying patterns, and representing ideas. In the following example, Moira is introducing a literacy lesson that looks at sequencing and is drawing students attention to the task and why they are completing this task.

Moira You have to pay close attention to the order that things happen in my story, because when we’re done you’re going to have little pictures and you’re going to put my story in order, in a flowchart. Does anybody know what a flowchart is? What’s a flowchart Jamie?

Jamie It’s something that’s easy and you can get through quick and um that will um get you through the steps really quick.

Moira Yeah! So it’s gonna flow, it’s called a flowchart. When I think of “flow” it’s like swaying. So it’s gonna flow through every step of my story. [...] So pay close attention to where Jet goes because you’re going to have to make a flowchart for me.

Moira continues with this idea of sequencing and representing ideas through a flow chart as she later tells her students that the flowchart they just did as part of the lesson was like an algorithm because you could use the step by step flowchart to retell what happened in the story.

Increase in Connections

One of the foundational pieces of this curriculum is that it was designed to highlight the cross-disciplinary nature of CT and engineering by providing lessons that help to facilitate STEM learning through an integrated approach. In the first year, the teachers were seen making several connections for the students to different areas of the unit. In this next example, Moira is reading a book on animal habitats with her students during the second literacy lesson.

Moira (Reading) “What does a bullfrog need in her home or her habitat? A safe place to sleep, said Wanda. Water, said Ralphie. Food, said [...]. Fresh air, said Arnold, as he opened his windows.” Now all of those things sound awful familiar (pointing to list on the board). Those are all part of our what?
In this example, Moira encourages students to connect what they are learning about animals and habitats back to back to the ideas of basic needs and why those are important. However, in year two, the teachers made many more connections across the unit as well as to students’ prior knowledge and to other class experiences that were external to the curriculum. These included examples such as references to the books covered in previous lessons or references to topics covered earlier in the school year. In this next example, Miriam utilizes an art concept the students are familiar with during a tangram activity.

Miriam  Do you remember when Mr. [...] was talking about positive and negative space?

Class  Yeah.

Miriam  Okay the positive space is what you’re making with your tangrams. The negative space is what’s around your cat so some of you need a little triangle by his tail and that’s not the negative space that you have. If your space doesn’t match the space on the picture that means something needs to be turned.

The teachers all extended the involvement of prior knowledge in the classroom by making connections to other areas, but also encouraged the students to bring up their own connections. Miriam in particular used student suggestions in class to demonstrate examples of good connections in practice. For example, when discussing “juicy words” in a literature lesson, Miriam asked her students what they think the word prancing means. The students mentioned horses and the reindeer, Prancer. Miriam then praised her students for using their connections to talk about new words. When another student describes prancing as a similar movement to dancing, the teacher then directs students back to the previous reindeer connection, to encourage another connection to the reindeer, Dancer.

Therefore, when looking across year one and two, even though the teachers encouraged student connections to text, movies, and lived experiences in both years, the teachers all increased the amount and scope of how they reviewed or discussed connections to students’ prior knowledge or learning in other areas across the curriculum in year two.

Emphasizing Teamwork and Failure

The different ways teachers set up and managed their classrooms changed from year one to year two. This included how they managed group work and what types of behaviors and expectations they choose to emphasize with their students. In year one, some of the common
management techniques seen across the classrooms included picking cohesive groups and roles for students and by intentionally separating materials for the students by giving each team of students a different color. One teacher, Miriam, mentioned to her students, while passing out materials, that she had separated the shapes by color because it should keep the students from mixing their materials up with neighboring groups. Shannon, in year one, was seen having students do the designing and building individually instead of in groups. In these examples, a large focus of the teacher actions during the first year was on the putting structures in place that would prevent possible issues. Whereas in the second year, the teachers were more focused on guiding the students to work together and handing over some responsibility to come up with the best solutions as a pair. Additionally, in year two, more emphasis is placed on encouraging teamwork by all three teachers throughout all of the lessons instead of just during the later stages of the design process. For example, in year one, Miriam assigned team member roles to her students during the last two lesson focused on completing the engineering design challenge. However, in year two, rather than assigning roles during the design aspects of the unit, Miriam had a discussion with her students that can be seen in the following example.

Miriam  Now this is going to involve teamwork and communication. We do not have time for Mark to test every single shape by himself, so what strategy can you use if you’re trying to explore and test these shapes as a team of two or three Valerie?

Valerie  Teamwork.

Miriam  Teamwork. And what does teamwork look like with two people. Alison?

Alison  It looks like you’re talking to each other...

Miriam  Okay you’re talking.

Alison  And you’re saying this goes there, this goes there.

Miriam  This goes there, this goes there. Okay is this teamwork if I hold the shapes and I do all the stacking?

Class  No.

Miriam  No, so how are we going to share the opportunity to tough the shapes and practice stacking. How are we going to do that Arnold?

Arnold  One of us gets um half and another gets half and we take turns stacking.

Miriam  Okay so Arnold says I’m going to do these three shapes and you’re going to do these three shapes and then we’ll test them together.
In this example, you can see that Miriam’s focus was on getting their feedback for what a good team member does and looks like and then she used the students’ responses throughout the rest of the unit to reinforce good teamwork behavior. Another change in classroom expectations that occurred in year two was that Shannon chose to emphasize acceptable failure throughout the design process during year two. For example, in her interview, Shannon remarked that “students did not have meltdowns when their designs did not work” and she attributed this to the heavy emphasis that she placed on acceptable failure and what that looked like throughout the design process.

Changes in Questioning Strategies

During year two, the teachers also increased the depth of the types of questions they asked and how they intervened with the students compared to what was seen in year 1. There were times in both years when all three of the teachers prompted students to ask questions or redirected students’ answers, however in year one, the teachers often directed students to a certain answer instead of exploring the student given response for meaning or connection to the original question. In year one, the students often started to ramble about thoughts that they had when answering questions, but the teachers frequently cut them off before they were able to direct the thoughts back to the task at hand. For example, in year one, Moira has asked students if they have any questions to send to their client.

Moira Think if you have any questions or anything you need to ask her, James.
James We know.
Moira What?
James We know.
Moira We know what?
James That she needs help.
Moira Was that a question?
James No.
Moira Is that something she can answer. No. We do know she needs help you’re right, but that’s not really a question. [...] A question is something she can answer. Sam?
Sam Maybe she could make one!
Moira Is that something she could answer? So you have to ask a question like, how many hamster cages are there maybe or how many
people shop at your store. See if you guys have any questions like that. Danielle you have a question?

Danielle How many cages do you have.

In this example, Moira was observed redirecting the student responses when they were problem scoping instead of exploring their statements and when she did let them expand on their thinking, she interrupted them to remind them to phrase as a question. In year two, the teachers were seen utilizing more open-ended questions in “why” format with their students. They also more frequently utilized student responses in their whole group discussions. For example, Miriam used student responses during a problem scoping activity to show that combining all of their suggestions with little alteration could help to better define the problem.

Miriam What are you thinking Aaron?
Aaron Um like, put a cage um and have a cage and make the door inside of a cage.
Miriam Okay so, combine cages? Okay so maybe we can combine cages.
Aaron And make the door in between them.
Miriam Okay, with a door. Do we have enough room in our classroom for a cage?
Class Yeah.
Miriam Do we have enough room in our classroom for two cages with a door? Okay we have to see if that’ll work. Size, you’ve been thinking about size, we’ll have to see if size is a factor, if that’s something we have to keep in mind. Jeremy what are you thinking?
Jeremy I’m thinking it’s kind of like combining but you use tubes to combine them.
Miriam Okay so use some tubes.
Jeremy Put a cage and then you put a tube and then you put another cage and attach them.
Miriam Use tubes. Attach cages. What are you thinking Arnold?
Arnold We can grab like four box and cut like some of it down and make like four boxes and then glue them.
Miriam Okay so we’re going to get four boxes.
Arnold And then um make like tiny doors [...] make rooms.

Miriam Okay so four boxes to make rooms. So it sounds like a lot of you are talking about building. [...] Alright so we’re talking about combining cages, attaching cages, maybe making rooms what else can we do Charlie?

Charlie We can just like get two cages [...] and put them both together.

Miriam Okay so combining cages. Okay so it sounds like you want to put things together. Veronica.

Veronica You can take like four cages and stack two on the top and then you can make a little stairs [...].

Miriam Okay so add stairs. Okay so Veronica’s thinking maybe we don’t have enough room to make it bigger, maybe we need to make it taller. Add stairs. Interesting. You’re thinking like builders for sure. Alright one more idea, Andrea.

Andrea You could combine everything together.

Miriam Okay combine. We got that word combine, attach, build rooms, add things.

When coming up with a list of ideas to send to the client, Miriam took all student questions and suggestions as long as they were related to the problem they defined. She also encouraged them to be creative. After she mentioned creativity, student suggestions quickly increased. Miriam then asked students what they would want if they were in the same situation. Students gave even more ideas that satisfied the criteria. In this example, Miriam demonstrated her ability to incorporate students’ responses and to prompt students to develop their ideas.

Making it Their Own Curriculum

The curriculum as written was designed to be accessible for most first-grade classrooms. However, it would be ideal for teachers to adapt the lessons to their unique students. In year one, the teachers closely followed the scripts and activities throughout the curriculum. However, in year two, even though they still followed the curriculum fairly closely in terms of implementing similar activities in each of their classrooms, they were also seen making modifications to the curriculum. Each teacher made slightly different adjustments, and these changes were more related more to instructional approach or pedagogy than content. Some of these modifications included integrating some of the bigger ideas outside of the coverage of the curriculum. For example, in year two, Miriam explained how reading, writing, and mathematics are all needed when creating an algorithm. During her interview, Miriam elaborated on her modifications to extend the ideas of algorithm more broadly, “For me, because it’s the second year you’re like ‘okay how can I do this differently’”. Moira was seen encouraging student
presentations and the importance of communicating and sharing ideas for each activity in year two. Specifically at each stopping point in a lesson, a different team of students would be chosen to describe and present their group work to the class. One of the big changes that Shannon made in year two was that she took polls and collected data from students in a few of the activities to integrate another layer of math into those lessons and the curriculum. Across all of these examples, the teachers were choosing to add things to the curriculum as part of their modifications in the second year. In the next excerpt, when students are working on one of their activities, Miriam mentions the differences in teacher approaches to the researcher.

Miriam: We just sorted as we read and kinda put words down so they could connect. [...] And then Shannon had them draw instead of write so we’re all kind of modifying as they go.

This example captures what was seen across the classrooms in year two that the teachers were still following the curriculum, but also making modification to the curriculum as they implemented the lessons in their classrooms.

Discussion

As we looked across the three classrooms and over two years of implementation, there were a number of themes that emerged related to changes in the teacher’s actions that suggest that an increase in experience with the content and curriculum led to some changes in the teachers practices. Additionally, some of the changes seen in the second year, such as the more intentional grounding of their learning within the engineering design challenge, increased description of CT terms and ideas, and a bigger emphasis on teamwork and failure within their instruction were more related to changes in their instructional approach to engineering design and CT. Whereas other changes, such as improvements in the types and depth of questioning, still appeared to impact their instruction in engineering design and CT but was more characteristic of improvements to more general pedagogical knowledge. This is interesting as we did see that even within implementation of novel content, engineering and CT, that the three teachers’ actions not only changed in terms improved general pedagogical moves, but also in some more engineering and CT specific changes from year one to year two. The changes in the teachers’ classroom actions were not surprising as they had more experience and felt more comfortable with the novel content and curriculum, but there were several interesting patterns within the changes that were observed.

When looking at the changes that were more related to engineering, increasing the amount and scope of how the teachers discussed the design challenge with their students, provided more opportunities for the students to understand the purpose of their work and make connections across the different pieces of the curriculum. They also modeled good problem scoping strategies by continually revisiting the problem and the learning that needed to happen to
understand the problem. These strategies can model for the students how to practice more authentic engineering [27] and can provide motivation for the learning by better grounding the students’ learning in the engineering design challenge.

The changes in teachers’ action related to CT included an increased focus on more intentionally and explicitly defining CT terms for students and relating those terms back to the engineering design challenge. The teachers also made more connections from the CT to other areas, which modeled the interdisciplinary nature of CT for their students. Additionally, the teachers in year two were also seen making more interdisciplinary connections between CT and other content areas, suggesting that they presented CT as being more integral to other content area to their students and had a more interdisciplinary view of CT rather than just computers or coding. This has been identified as an important distinction for teachers when thinking about integrating CT into classrooms [2].

Additionally, the changes suggest that the teachers felt comfortable to make changes to the curriculum to improve it for their unique group of students, such as when they added connections to students’ prior knowledge or brought up the engineering design process at more places throughout the curriculum. These connections acted to increase the integration of the subjects. As students at the first grade level are building the foundations of the future learning, this level of integration has the potential to help students scaffold their understandings of future STEM topics.

Another one of the changes that we observed was that the teachers changed their questioning strategies, including the depth of the questions that they asked. By increasing the depth of their questions, the teachers gave the students more opportunities to think deeply about the questions and their effects. Additionally, the teachers were modeling for their students how to ask in depth questions and make connections across the subjects they were learning and their lives in and out of the classroom. Because young students often model their behavior off their teachers [13], [14], this provides support for students to think deeply about the topics they are learning and apply their thinking in new ways. However, it has significant repercussions for how they influence their students. For example, studies have shown that as teachers become more comfortable with the subject matter, their abilities to ask deeper questions increases the depth of thinking of their students [15].

Conclusions and implications

We studied how three first grade teachers changed their actions over the course of two school years after participating in professional development programs and implementing a STEM integration based curricular unit. We found that the teachers made changes to how they described computational thinking, classroom management, how they made connections across the curriculum and connections to the design challenge, how they adhered to the curriculum, and their questioning strategies. These findings provide insight into how teachers’ actions change over a period of time. Implications of this study include improving professional development
programs, better understandings of how to incorporate good teaching practices into curricular implementation and may provide insight on how to encourage veteran teachers to incorporate good integrated STEM and CT practices.

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