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Inspiring Computational Thinking in Young Children's Engineering Design Activities (Fundamental)

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Inspiring computational thinking in young children's engineering design activities

Introduction

Complementing science and mathematics, computational thinking and engineering are increasingly integrated into K-12 classrooms as well as K-12 out-of-school environments. In the United States, these efforts are motivated by the Computer Science Teaching Association's K-12 standards, the inclusion of engineering in the Next Generation Science Standards as well as state standards. However, there are few clear examples of what engineering thinking and computational thinking looks like when enacted by young students. Computational thinking is broader than simply programming and early experience with computational thinking can shape student attitudes toward STEM and computing for years to come. Collecting and sharing pre-college students' thinking in these areas is important for researchers as we develop a shared research agenda; important for teachers in knowing how to guide their students and knowing what to look for among their students; and important for helping parents understand how to support engineering thinking and computational thinking. The recognition of this need was a major outcome of the recent "Engineering Design and Practices Roundtable: Working Together to Advance Pre K-12 Engineering Design" convened by the Museum of Science in Boston in January 2015. Without a shared understanding of what engineering design practices (or computational thinking in this case) look like in pre-college settings, researchers and curriculum developers will result in numerous inconsistencies across the broad spectrum of implementation.

The project reported in this paper aims to integrate computational thinking into an existing integrated STEM curriculum. In order to develop computational thinking supplements appropriate for young children, the team analyzed the existing curriculum and videotaped observations of student teams participating in the integrated STEM curriculum to identify the nascent computational thinking students exhibited. These qualitative examples serve to both inform the larger research community what computational thinking can look like among 5-8 year olds, and provide baselines for further development of engineering and computational thinking curriculum and assessments.

Background

Computational Thinking

In the NRC Report of a Workshop of Pedagogical Aspects of Computational Thinking (2011), Cunningham described engineering as a focus of computational thinking for elementary education. She pointed to parallels between computational thinking and solving engineering problems, and the ways that computational thinking was critical to engineering habits of mind. Engineering habits of mind refer to the values, attitudes, and thinking skills associated with engineering and include systems thinking, creativity, optimism, collaboration, communication, and an attention to ethical considerations. Wing (2006) also connects computational thinking to engineering thinking, as she defines computational thinking as not simply programming but the overlap between mathematical thinking and engineering thinking. Likewise, Barr and Stephenson (2011) compare computational thinking capabilities across computer science, mathematics, science, social studies, and language arts. For example, learning to implement a particular algorithm in a computer science context would be analogous to following an experimental procedure in science or writing out step-by-step instructions for a language arts assignment.

The Computational Thinking Teacher Resources developed in a collaboration between the Computer Science Teachers Association (CSTA) and the International Society for Technology in Education (ISTE) (2011) define computational thinking as a "problem-solving process that includes (but is not limited to) the following characteristics:

- Formulating problems in a way that enables us to use a computer and other tools to help solve them
- Logically organizing and analyzing data
- Representing data through abstractions such as models and simulations
- Automating solutions through algorithmic thinking (a series of ordered steps)
- Identifying, analyzing, and implementing possible solutions with the goal of achieving the most efficient and effective combination of steps and resources
- Generalizing and transferring this problem-solving process to a wide variety of problems" (p. 7).

This definition of computational thinking, as well as the dispositions described by the CSTA & ISTE and the core computational thinking concepts listed in the Teacher Resources (2011) are consistent with core concepts of engineering design and mathematical modeling.

STEM + Computational (STEM + C) Thinking project

The proposed project is designed to address three critical aspects of STEM+C education: (1) clarity in what integrated thinking, engineering thinking and computational thinking look like when practiced by Kindergarten through 2nd grade (K-2) learners; (2) support for the adults who direct and engage K-2 students' learning; and (3) understanding variability of STEM+C education in informal and formal learning settings. The project focuses on the crucial early years (K-2) of students' learning for four reasons: (1) there is a scarcity of research on engineering and computing learning (NRC 2011) at these early ages in both formal and informal environments (2) these early learning experiences provide a foundation for the parent and child's expectations for future learning; (3) children begin to develop persistent beliefs about their abilities to engage in STEM+C learning and their interests in STEM+C that can either support or hinder their later STEM+C learning as early as the second grade; and 4) this is an age where children might either begin to develop their question-asking behavior into problem formulation skills that align with engineering and computing thinking or alternatively begin to lose that question-asking mindset. The project accomplishes these objectives by making modifications and developing supplements to the existing curriculum that present specific opportunities for students to engage in computational thinking.

This project is in its early stages having just started in Fall 2015. The goal of the work presented in this paper is to identify where computational thinking already exists in the PictureSTEM curriculum—an integrated STEM and literacy curriculum—and what this looks like as enacted by K-2 students. As the previous computational thinking definition highlights, the problem solving strategies and skills used in computational thinking will likely share many things in common with the STEM disciplines. Thus, even though the prior implementations PictureSTEM focused on STEM and literacy thinking and learning, there is likely to be aspects of computational thinking also present. This paper provides examples of aspects of computational thinking (i.e., troubleshooting) that are present without a claim that these are ideal or complete integrations of computational thinking.

Methods

Description of PictureSTEM unit(s)

The PictureSTEM curriculum was developed for grades K-2, with emphasis on the use of engineering design and literary contexts as a means to facilitate the integration of science, technology, engineering and mathematics content. High quality picture books are partnered with an engineering design challenge in order to allow student to engage in authentic, context-based activities that promote science and mathematics in an engaging way. There are four components that comprise the core of the PictureSTEM project and differentiate from current STEM implementation efforts: engineering design as the interdisciplinary glue, a focus on engineering contexts, high-quality literature to promote engagement, and instruction of specific STEM content within an integrated approach. The development of the PictureSTEM modules were guided and informed by the STEM integration research paradigm, which is defined by the merging of the disciplines of science, technology, engineering, and mathematics in order to: (1) deepen student understanding of STEM disciplines by contextualizing concepts, (2) broaden student understanding of STEM disciplines through exposure to socially and culturally relevant STEM contexts, and (3) increase student interest in STEM disciplines to expand their pathways for students entering STEM fields (Roehrig, Moore, Wang & Park, 2012). Additionally, the units were built upon on the Framework for Quality STEM Integration Curriculum which recommends that the following six tenets be included when developing integrated STEM curriculum: a motivating and engaging context; participation in an engineering design task; allowing students to learn from failure and then provide an opportunity to redesign; include appropriate, standards-based mathematics and science content; employ student-centered pedagogies; and promote teamwork and communication skills(Moore, Guzey, and Brown, 2014; Moore, Stohlmann, Wang, Tank, Glancy, and Roehrig, 2014).

Two of the PictureSTEM units - Designing Paper Baskets and Designing Toy Box Organizers - were evaluated for computational thinking.

The Designing Paper Baskets unit focuses on the development of pattern recognition and the exploration of physical materials, situated within a hands-on engineering design task (see Tank et al., 2016 for more details on the unit). Students are asked to assist fellow kindergarteners, Max and Lola, in designing a paper basket template to give to potential rock collectors. During the unit, students investigate the properties of paper and water, test paper strength and conduct tests, as well as identify/create patterns, all situated within the engineering design context.

In Designing Toy Box Organizers, students explore physical properties and measurement through design of an organizer to address complaints received by a toy company (see Tank & Moore, 2015 for more details). The students investigate standard units of measure and the various tools for measuring length, as well as exploring the varied physical properties of objects and materials that would be accounted for in the design of the organizer.

Data sources

Video data was collected over a two-week period from three kindergarten classes (Paper Baskets) and one second grade class (Toy Box Organizers) during Spring 2015, at a public charter school located in the Midwest. One video camera was focused on the teacher who was addressing the class as a group and then repositioned to capture a wide range of students as they completed group work.

Data analysis

The team followed two approaches in identifying computational thinking in the curriculum. First the team reviewed one (name redacted) unit, Designing a Toy Box Organizer using a content analysis approach (Holsti, 1969) identifying where computational thinking could take place within the (name redacted) unit. The team used an interaction analysis approach (Jordan & Henderson, 1995) for analyzing the videorecorded observations to identify rich examples the of students engaging in computational thinking. In order to identify examples of computational thinking, the team used the CT Vocabulary and Progression Chart provided by the CSTA & ISTE (2011). While the team easily identified examples of data collection, data analysis, data representation, and problem decomposition in the content analysis of the (name redacted) units, these examples were focused within a science or engineering context as per the curriculum design. The team was most interested in isolating student examples that would better fit a computational thinking context for the review of the videotaped observations. Thus, the team set out to identify examples of abstraction, algorithms and procedures, automation, simulation, and parallelization. Table 1 below describes all the computational thinking codes used for both sets of analyses.

Table 1: Description of Computational Thinking Codes

Computational Thinking	**Description**
Data collection	The process of gathering appropriate information
Data analysis	Making sense of data, fining patterns, and drawing conclusions
Data representation	Depicting and organizing data in appropriate graphs, charts, words, or images
Problem decomposition	Breaking down tasks into smaller, manageable parts
Abstraction	Reducing complexity to define main idea.
Algorithms and procedures	Series of ordered steps taken to solve a problem or achieve some end.

Automation	Having computers or machines do repetitive or tedious tasks.
Simulation	Representation or model of a process. Simulation also involves running experiments using models.
Parallelization	Organize resources to simultaneously carry out tasks to reach a common goal.

Results and Discussion

Examples from the Curriculum

Table 2: PictureSTEM Designing A Toy Box Organizer Lesson Descriptions Coded for Computational Thinking

Lesson 1 (1A) STEM+C - Treasure Hunt modeling activity: The students are introduced to the design challenge and help develop ideas about what they might need to know in order to design an organizer. Through their definition building, students help the teacher break down the problem into smaller parts (***problem decomposition***). Building on their defining of the problem, students learn about the problem of not having a standard unit of measure through making a treasure map marked out in paces. They learn that different people's paces are different and so finding the treasure is difficult. They use the steps to act out the roles of the characters in the story to physically demonstrate these differences (***simulation***). The students must develop a way to standardize the treasure map in order to eliminate this issue. It brings in computational thinking through the use of algorithmic/procedural steps to create standardized solutions for the treasure hunt (***algorithms and procedures***). The students then tie this back to the engineering design challenge to see how this might help them design a toy box organizer.
Lesson 2. STEM+C - Design your own "standard": Building on the need for a way to measure things in lesson 1, students explore a variety of non-standard and standard measuring tools. Each student pair is given a different non-standard unit (such as paper clips, cubes, rocks, etc.) to measure a common item in the classroom. Through a justification process, students engage in a discussion about why each pair came up with a different answer for the measurement. Students then use a common or "standard" measuring tool as a class that they will use to measure the same fixed distance in order to see how using the same tool produces similar results. Through compare and contrast methods, students are analyzing the data collected through the measurement activities to look for patterns and similarities that lead them to the need for common measurement tools (***data collection, analysis, and representation***). The students again tie this to the engineering challenge to determine the usefulness of a standard measure for solving their toy box organizer problem.
Lesson 3 STEM+C – Physical Properties of Materials: Students are introduced to the science concept of

physical properties through the book Living Color as they learn about how objects can be sorted in a number of different ways, which includes abstraction across different objects to recognize that they fit into categories (***abstraction***). As students are sorting these items, they are learning about physical properties and deepening their understanding of what it means if all of the items in a pile are red or soft or strong (EDP – learn). After students have learned about these physical properties, they do an activity where they ask a series of yes or no questions about the properties of an object in a mystery bag until they are able to identify that mystery object (***algorithms and procedures***).
Lesson 4 STEM+C – Test Materials & Plan Design: Students prepare for the design challenge by thinking like engineers while they test the materials that they will be using in their toy box organizer designs (EDP – learn). This lesson helps to build background knowledge that students will use in solving their engineering design challenge by testing the building materials based on their physical properties and using their results to determine which materials will be better for certain tasks. They find that the craft sticks are nice and sturdy if they want to make strong dividers, but aren't very flexible in terms of fitting them together and into their toy boxes (***data collection and analysis***). After testing their materials, students review the problem and individually brainstorm some possible toy box designs before talking to their partner and deciding on a plan for their group design, which helps students to see that they can break their design challenge into smaller and more manageable pieces (***problem decomposition***).
Lesson 5 STEM+C - Students design, build, and test an organization system for a toy box. Then students share their designs and results with the class before using their test results to engage in a redesign (***data analysis***). After redesigning their new toy box, students will have the opportunity to give their directions and measurements (***algorithms and procedures***) to another group who will pretend to be the toy company and will attempt to build their toy box design (***simulation***).

Content analysis of the five lessons for the Designing a Toy Box Organizer unit yielded natural opportunities for students to engage in all the computational thinking practices from Table 1 except for parallelization and automation. These two were consistently difficult to imagine in the other units of the curriculum. However, the team did identify opportunities that could prompt students to think about parallelization by dividing the work of the activity into two parallel tasks. However, the curriculum would need to plan for scaffolding this division to ensure that the teams would be on track to bring the parallel work back together again. Integrating automation would likely entail describing how machines (e.g., CNC machines) might automate the process. Despite no clear connections to these two ideas of computational thinking, there was sufficient opportunity to modify the curriculum to more explicitly address and integrate this STEM unit into a STEM + CT unit.

Examples of students engaging in computational thinking

Designing Paper Baskets: Identifying and Using Patterns

The research team identified a number of computational thinking practices within the Designing Paper Baskets unit. As described earlier, this unit has students design a paper basket that they weave with various types of paper (e.g., wax paper, tissue paper, card stock, etc.) they can choose from. The curriculum includes the reading of the book Pattern Fish that introduces the idea of various patterns (e.g., ABAB, ABBA, AABB, etc.) through the physical appearance of the fish. The teacher then relates these patterns to the process of weaving. An example of the dialogue between the teacher and students is as follows:

> Teacher: Listen for the pattern. Over, under, over, under, over, under. What pattern do you hear?
> Students: ABAB!

The students' ability to identify and name ABAB as the pattern is an example of **abstraction**. With the teacher's prompting the students are able to abstract this generic form of patterns from what they hear (repeating of over/under) and what they see in the basket weave. Following this discussion the teacher refers the students to a worksheet where they will select their desired pattern (or create their own). Once selected the students follow the weave pattern in creating their paper basket. While the curriculum does not explicitly make an analogy between the worksheet patterns and an **algorithm**, the research team identified this process as such. For a pair of students who created their own pattern, they had to visually represent a pattern on the worksheet, "the code," and then follow this algorithm/procedure. They did this by repeating the words "over over under over over under…" to help them weave with an AABAAB pattern.

Designing Toy Box Organizer: Parallelization

Students participated in **parallelization** in constructing their toy organizer. Students take different responsibilities of the building task and work in parallel to complete the construction of the box. The simultaneous work of the student is also an example of students engaging in computationally thinking about the algorithms and procedures required to construct the organizer. Students are seen working in teams and asking questions of each other and the teacher to learn more constraints of their design. Inherently, students are additionally involved in problem decomposition by breaking down their respective tasks into smaller manageable parts.

Treasure Hunt: Simulation

At the beginning of the Treasure Hunt lesson, based on the problem scenario, three different students acted out the treasure map story. Teacher asked them to take different types of step-small, normal and large. By acting out their role, they illustrated how with the same directions they can arrive in different locations. This representation is an example of **simulation**. In this lesson, simulation helped students to see if they do not create a correct direction, not everyone can find a buried treasure. Participating in the **simulation** also helped students to develop algorithm and procedure of solving their treasure hunt problem. For instance, after role-playing, students started developing their own instructions by considering the different types of step the guests may take.

Implications/Conclusions

The examples as highlighted within PictureSTEM lessons and as observed in the implementation of two PictureSTEM units demonstrate that children in these early elementary grades can begin to enact what we have defined as computational thinking. Students are able to abstract patterns and then use them to create rudimentary algorithms to carry out a task. As illustrated within the curriculum, the mathematics ideas of patterns, which is introduced in kindergarten (and at times in pre-school), provides the possibility to involve contexts for students to apply computational thinking. As with many integrated curricula, PictureSTEM provides opportunities for STEM content and contexts to parallel those of computational thinking. The team expects that this is not unique to the PictureSTEM units and that other STEM curriculum, integrated or not, provide openings to have young students engaged in computational thinking.

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