Promoting Computational Thinking in children Using Apps

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Introduction

Researchers within the field of Engineering Education are looking for more ways to incorporate engineering and engineering thinking into both K-12 formal and informal setting. Increasing demand for curricula and programming that supports computational thinking in K-2 settings motivates our research team to investigate how computational thinking can be understood, observed, and supported for this age group. One way to integrate computational thinking in K-2 education is with the use of educational apps. We used our preliminary understanding of computational thinking to develop our guiding codebook. The codebook includes INSPIRE definition, and examples and non-examples observed in the apps. Through a systematic approach, we reviewed 89 apps and finally identified 12 educational app that promote computational thinking in the context of problem-solving. The apps and the computational thinking competencies that each app promotes are listed in this study. For the field of engineering education at large, the results of this study illuminate the following points:

1. Computational thinking is possible to observe and teach at the K-2 levels.
2. Educational media, especially apps, can be used to promote computational thinking competencies.

The codebook can serve as a tool to review other educational media that promote computational thinking. In addition, the apps identified in this study can be integrated into both formal and informal learning activities. The next studies include reviewing and identifying more apps, reviewing books and games, and observing children playing with the apps and games to investigate what computational thinking competencies look like in children.

Background

Incorporating engineering and engineering thinking into both K-12 formal and informal settings has gained increased attention from engineering education researchers. More recently, incorporating Computational Thinking (CT) has gained increased attention in both formal and informal settings. Therefore, many educational resources have focused on integrating engineering and computational thinking with other subjects in their standards and curricula (e.g. CSTA, 2012, NGSS 2012). As an example, the Next Generation Science Standards include engineering and computational thinking aligned with the science practices. Additionally, Dasgupta and Purzer (2016) stated that if CT competencies are integrated into STEM education, it can positively impact STEM learning for K-12 students. Therefore, understanding what computational thinking competencies look like in K-12 education is useful for the future of STEM Education.

In 2011, the National Research Council Report of a Workshop of Pedagogical Aspects of Computations characterized engineering as a key focus of computational thinking in elementary education. In this report, Cunningham connected computational thinking and engineering problems to assert that computational thinking was crucial to engineering habits of mind. These habits of mind describe how values, attitudes, and thinking skills are linked to engineering. Computational thinking has also previously been linked to engineering beyond simply programming by Wing in 2006. Wing defined computational thinking as the overlap between mathematical thinking and engineering thinking.

In 2011, The Computational Thinking Teacher Resources developed as the result of a collaboration between the Computer Science Teachers Association (CSTA) and the International Society for Technology and Education (ISTE). This collaboration produced a list of characteristics that define and describe computational thinking and its qualities. In 2012, Google also released a list of computational thinking competencies and they provide teaching tips on how to elicit this type of learning in students. However, the competencies identified by Google do not entirely match those presented in the Computational Thinking Teacher Resources, and differences in how computational thinking is defined and operationalized also varies across the research literature.

Purpose of the study

As a part of a larger study, we are interested in observing computational thinking in museum exhibits and homeschool settings, as well as understanding what tools promote computational thinking within these spaces. These potential tools include, but are not limited to, digital media and games. As a result, our team has aimed to review digital media, books, and games that claim to promote the development of computational thinking in children.

Digital media is taking over adults' lives and children's of all ages. Digital media such as tablets and applications have entered the educational system and become popular worldwide. Chiong and Shuler (2010) demonstrated that apps could successfully sustain children's' learning as well as their interest. Moreover, Couse and Chen (2010) called for "more fully integrate technology into the curriculum to encourage the active engagement and thinking of young children" (p.76). Hence, in order to integrate apps into educational material and curriculum, it is important to select the apps that promote children's learning. Therefore, the goal of this study is to review and select the apps that potentially promote computational competencies in K-2 children.

Preliminary Understanding of CT

To understand how computational thinking may be incorporated into K-2 settings, our research team used the computational thinking competencies described by CSTA and Google as our initial framework. We choose these models as they included breakdowns of CT competencies for our target group.

Using these preliminary definitions, our research team reviewed videos of K-2 students engaged in PictureSTEM curricular units (Hynes et al., 2016). PictureSTEM is an integrated STEM+literacy curriculum developed for grades K-2 with the focus on engineering design and literacy (Tank, Moore, & Pettis, 2013). The goal of reviewing these videos was to see what computational thinking looks like when children engaged in engineering activities. Through this review, we highlighted student interactions that seemed to be examples of CT. Figure 1 shows an example of what we have found.

Table 1. Review Book

Clip Number: Lesson 1B-2 literacy discussion Student Activity: experimenting with using different objects as measurement tools.				
Time: Competency	6.00-8.00	13.30-17.00	15.00-17.01	16.33-18.00
Data collection	Working together and finding the length of toy box by the objects they have as units			

Data analysis	Measuring the toy box together	Explaining their units and making sense of patterns about the size of the unit. The girl: "Some units are bigger."	The little girl describes her work: "We just have a different units! Box were not different." This object is bigger than this object, it gets more about of we are measuring. Therefore this one is obviously bigger than this one.	The little girl realizes that the card she was measuring with has two different sizes to measure so it gives her two different measures.
Data representation		Teacher represented data in a chart.		
Abstraction				Making sense of what Standard is.
Simulation				The girl shows the card to her friends, and illustrates how using this card and its two different sides gives them two different answer

Reviewing this videos provided evidence that students in this age group are able to engage in different computational thinking competencies. Also, the examples provided us with enough insights to synthesize, develop and finalize our CT definitions (INSPIRE Definitions, 2017). To compare the definitions, Appendix 2 presents three sets of CT definitions including INSPIRE, Google and CSTA.

Reviewing Educational Apps

We used the INSPIRE CT definitions as a framework to review and select educational media that engage children in those competencies. The educational media includes apps, games, toys, books, and websites. In this study, however, we focused on selecting and reviewing educational apps. First, we identified a sample of apps to review, developed a coding procedure, then coded selected apps for evidence of computational thinking. The following section describes these steps in detail.

Identifying a sample

To select our samples, we looked for the websites that meet four criteria: (1) offer age-based libraries, (2) include experts' reviews and ratings, (3) include the parents' reviews and ratings, and (4) have a search engine within the website. Among the websites we found that www.commonsensemedia.com met all four criteria. To find the apps that claimed to promote computational thinking, we used "computing", "programing", or "computational thinking" as our research keywords. We then used the inclusion criteria below to select the apps:

1) The app should be appropriate for ages 5-8
2) The app should be rated 3.5 or higher by the customers or parents based on the rating scheme below:

   Is it any good?

      Just fine (3 stars)
      Really good (4 stars)
      The best (5 stars)

3) The app should be rated 4 or higher by experts based on the criteria below:

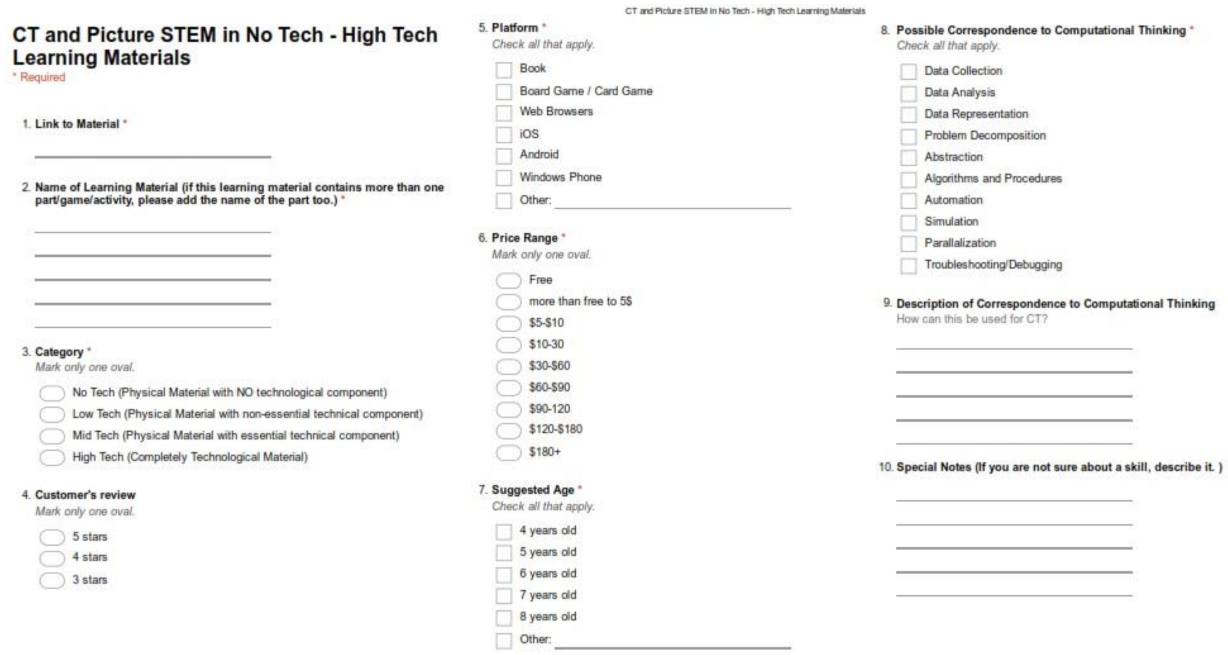
   4 dots: Engaging, very good learning approach.
   5 dots: Really engaging, excellent learning approach.

Based on this criteria, we identified 86 apps to review.

Review procedure

The aim of the review process was to first exclude the apps that do not potentially promote computational thinking in children, and then to organize the remaining apps based on price, customer review and suggested age. To do so, we first created an initial review book which constitutes of age range, the price, platform, the rate given by costumers, the link for download/install, the potential computational thinking competencies, and a section to describe the potential competencies (see figure 3).

Figure 3. Review Book



CT and Picture STEM in No Tech - High Tech Learning Materials

CT and Picture STEM in No Tech - High Tech Learning Materials
* Required

1. **Link to Material** *

2. **Name of Learning Material (if this learning material contains more than one part/game/activity, please add the name of the part too.)** *

3. **Category** *
Mark only one oval.
- No Tech (Physical Material with NO technological component)
- Low Tech (Physical Material with non-essential technical component)
- Mid Tech (Physical Material with essential technical component)
- High Tech (Completely Technological Material)

4. **Customer's review**
Mark only one oval.
- 5 stars
- 4 stars
- 3 stars

5. **Platform** *
Check all that apply.
- Book
- Board Game / Card Game
- Web Browsers
- iOS
- Android
- Windows Phone
- Other:

6. **Price Range** *
Mark only one oval.
- Free
- more than free to 5$
- $5-$10
- $10-30
- $30-$60
- $60-$90
- $90-120
- $120-$180
- $180+

7. **Suggested Age** *
Check all that apply.
- 4 years old
- 5 years old
- 6 years old
- 7 years old
- 8 years old
- Other:

8. **Possible Correspondence to Computational Thinking** *
Check all that apply.
- Data Collection
- Data Analysis
- Data Representation
- Problem Decomposition
- Abstraction
- Algorithms and Procedures
- Automation
- Simulation
- Parallalization
- Troubleshooting/Debugging

9. **Description of Correspondence to Computational Thinking**
How can this be used for CT?

10. **Special Notes (If you are not sure about a skill, describe it.)**

Next, we reviewed the apps by spending some time interacting with each app. In order to make decisions for excluding or including apps, we set a 10-minute critical time limit. We excluded the apps if no evidence of computational thinking competencies were found in them after 10 minutes. In average, the amount of time we spent on each app was between 10 to 30 minutes. Finally, this portion of the review process left us with 41 apps, each with at least one potential competency evident. These apps were then organized based on the other elements in the review book.

Coding procedure

Computational thinking is a process of problem-solving. Therefore, in the next phase of the study, we looked at computational thinking competencies through problem-solving lens using the set of definitions developed by our research team as a result of the video observations. The aims of the coding phase were to identify:

- A list of apps which develop computational thinking competencies in the context of problem solving in children.
- The computational thinking competencies which most frequently appeared in educational apps appropriate for K-2 aged children.

Each of the two researchers engaged in this process first coded one app individually. Next, we shared our experiences and findings to come into agreement about what certain activities in the apps required users to do. We then were able to generate examples and non-examples of computational thinking. As we developed a collaborative understanding, we modified the codebook with examples and non-examples reflected in Appendix 2.

Next we used the codebook from Appendix 2 to code all 41 apps. Researchers spent exactly 30 minutes playing with each app and then another 30 minutes reflecting on their experience using the guiding codebook (Appendix 2) to identify existing competencies within the app.

Results

After coding the apps, we found that only 12 apps developed computational thinking through problem-solving. These apps and the competencies present in them are listed in Table 2. Abstraction, algorithm, pattern recognition, troubleshooting, and simulation were seen the most frequently in these apps. We did not see any evidence of data collection, data analysis, and parallelization in these apps.

Table 2. Competencies Present in Apps

Name	Platforms	Price	Age	CT Competencies
Cargo-bot	iOS	Free	5+	Abstraction, Algorithms and Procedures, Debugging/Troubleshooting, Simulations, Pattern Recognition
Codeable Crafts	Android	Free	5+	Abstraction, Algorithms and Procedures, Debugging/Troubleshooting, Simulations, Pattern Recognition
Daisy the Dinosaur	iOS	Free	7+	Abstraction, Algorithms and Procedures, Debugging/Troubleshooting, Simulations, Pattern Recognition, Problem Decomposition
Kodable	iOS	Free	5-8	Abstraction, Algorithms and Procedures, Automation, Data Representation, Debugging/Troubleshooting, Simulations,

				Problem Decomposition, Pattern Recognition
Lightbot Jr.	Web browsers, iOS, Android	Free	4-8	Abstraction, Algorithms and Procedures, Data Representation, Debugging/Troubleshooting, Simulation, Pattern Recognition.
PBS KIDS ScratchJr	iPad, Android	Free	6+	Abstraction, Algorithms and Procedures, Debugging/Troubleshooting, Simulations, Pattern Recognition
Robozzle	Web browsers, iOS, Android, Windows phone	Free	6+	Abstraction, Algorithms and Procedures, Automation, Debugging/Troubleshooting, Problem Decomposition, Simulations, Pattern Recognition
Run Marco!	Web browsers, iOS, Android	Free	6+	Abstraction, Algorithms and Procedures, Data Representation, Debugging/Troubleshooting, Simulations, Pattern Recognition
Scratch Jr.	iPad, Android	Free	6+	Abstraction, Algorithms and Procedures, Data Representation, Debugging/Troubleshooting, Simulations, Pattern Recognition
Sushi Monsters	iOS	Free	4+	Problem Decomposition
The Foos	iOS, Android, Windows Phone, Kindle	Free	5+	Abstraction, Algorithms and Procedures, Data Representation, Debugging/Troublesho

	fire , Fire phone			oting, Problem Decomposition, Simulations, Pattern Recognition
Tynker	iOS, Android	Free	7+	Abstraction, Algorithms and Procedures, Debugging/Troubleshooting, Problem Decomposition, Simulations, Pattern Recognition

Conclusions and Implications

In this study we aimed to select and review the apps that potentially promote computational thinking competencies in K-2 children. The codebook we used included the INSPIRE definitions and examples and non-examples of the competencies. We finally identified 12 apps that promote CT in the context of problem-solving. The findings of this study indicate that the apps can develop all CT competencies listed in the INSPIRE index with the exception of problem decomposition, data representation and parallelization (for these three competencies, we do not have evidence that they cannot be developed in an app – we just did not find evidence confirming that apps can help children develop these competencies).

The apps identified in this study can be used by teachers and parents who are interested in engaging their children in experiences that develop computational thinking. For researchers looking to instill more computational thinking in educational media, the lack of evident parallelization, data collection and analysis competencies points to the opportunity to develop activities that better promote these competencies. For the field of engineering education at large, the results of this study illuminate the following points:

- Computational thinking is possible to observe and teach at the K-2 levels.
- Educational media, particularly apps, can be used to promote computational thinking competencies.
- The guiding codebook developed in this study can be used to review educational media for computational thinking.

Future Studies

To expand the findings of this study, further research could include reviewing apps from other sources. In addition, future studies should include investigating what computational thinking looks like when children play with these apps, and what competencies can be observed developing in these children. Beyond educational applications, further phases of this research will use the guiding codebook in Appendix 2 to code other educational media such as books and games for evidence of computational thinking competencies. An additional phase of this research will also include looking at existing engineering curricula for K-2 settings for opportunities to incorporate more computational thinking competencies.

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Appendices

Appendix 1

Comparing Computational Thinking Computational Definitions

CT Competencies	Inspire Definitions	Google Definitions	CSTA Definitions
Abstraction	Identify and utilize the structure of concepts/main ideas.	Identifying and extracting relevant information to define main idea(s)	Reducing complexity to define main idea
Algorithms and Procedures	Following, identifying, using, and creating an ordered set of instructions. (ie, through selection, iteration and recursion)	Creating an ordered series of instructions for solving similar problems or for doing a task	Series of ordered steps taken to solve a problem or achieve some end.
Automation	Assigning appropriated set of tasks to be done repetitively by computers	Having computers or machines do repetitive tasks	Having computers or machines do repetitive or tedious tasks.
Data Collection	Gathering information pertinent to solve the problem	Gathering information	The process of gathering appropriate information
Data Analysis	Making sense of data by identifying trends	Making sense of data by finding patterns or developing insights.	Making sense of data, finding patterns, and drawing conclusions
Data Representation	Organizing and depicting data in appropriate ways to demonstrate relationships among data points via representations such as graphs, charts, words or images	Depicting and organizing data in appropriate graphs, charts, words, or images	Depicting and organizing data in appropriate graphs, charts, words, or images
Debugging/Trouble Shooting	Identifying and systematically addressing problems that inhibit progress toward task completion		
Problem Decomposition	Breaking down data, processes or problems into smaller more manageable	Breaking down data, processes, or problems into	Breaking down tasks into

	component to be used to solve a problem	smaller, manageable parts	smaller, manageable parts
Parallelization	Simultaneous processing of smaller tasks to more efficiently reach a goal	Simultaneous processing of smaller tasks from a larger task to more efficiently reach a common goal	Organize resources to simultaneously carry out tasks to reach a common goal.
Simulations	Developing a model or representation to imitate natural and artificial processes	Developing a model to imitate real-world processes	Representation or model of a process. Simulation also involves running experiments using models.
Pattern Recognition	Observing patterns, trends and regularities in data (Google)	Observing patterns, trends and regularities in data	

Appendix 2.

CT Guiding Codebook

CT competencies	Definition	Examples	Non-Examples	Exemplary Apps
Abstraction	Identify and utilize the structure of concepts/main ideas.	A player abstracts the function of different commands based on what s/he sees in the real world. (upside arrow means jump, forward arrow means move)	If the app had explicitly explained what each command does to the player without requiring them to use the commands to understand how they work.	The Foos
Algorithms and Procedures	Following, identifying, using, and creating an ordered set of instructions. (ie, through selection, iteration and recursion)	A player creating series of commands to help the police Foos to get to the stolen doughnut.	If the app awarded progress to players who had randomly chosen a sequence of commands inappropriate to the problem (helping the police Foos to find the doughnut)	The Foos
Automation	Assigning appropriated set of tasks to be done repetitively by computers	Running a program that includes a series of functions in a loop in which the robot can repeat an act several times.	Repeating a series of commands by manually restarting the function.	DotDash Blocky
Data Collection	Gathering information pertinent to solve the problem	The robot performs a command; the player collects data from that performance to learn what each command does.	No useful information can be gained from watching a robot performance.	DotDash Blocky

Data Analysis	Making sense of data by identifying trends	A player finds patterns in the robot performance and associates the performance to the series of commands that were selected.	Data is organized and presented to the player in a way that makes patterns and insights obvious	DotDash Blocky
Data Representation	Organizing and depicting data in appropriate ways to demonstrate relationships among data points via representations such as graphs, charts, words or images	Understanding progress through the game via leveling maps.	Solving a problem using the collected information, without being ask to form/organize that information into any representations.	The Foos
Debugging/Trouble Shooting	Identifying and systematically addressing problems that inhibit progress toward task completion	In order to complete a level, the player must continue refining his list of commands until the appropriate goal has been reached. Stars encourage players to go back and debug by illustrating the quality solution selected by the player	Instead of finding and fixing the problem, the player resets the level, and creates a new sets of instructions. A player finds/creates a solution and wins the Ninja Foos levels of game. Even if s/he hasn't gained all the stars, s/he goes to the next level and gets involved in solving the new task.	The Foos
Problem Decomposition	Breaking down data, processes or problems into smaller more manageable component	To progress through the game, the player has to decide which series of commands (ie, jumping, walking, etc) will help	If the app broke down all the steps necessary to solve the problem and all the player needs to do is select appropriate command	The Foos

	to be used to solve a problem	the police reach the doughnuts	(In the first levels of the Foos and in higher levels of Ninja Foos, the player does not need to break any task down, since the task only requires one command.)	
Parallelization	Simultaneous processing of smaller tasks to more efficiently reach a goal	A player writes two small programs and combines them at the end so that simultaneously a robot dance and sing.	A player runs two different programs sequentially instead of in parallel, so the robot first moves forward and then dances.	DotDash Blocky
Simulations	Developing a model or representation to imitate natural and artificial processes	The robot play music after giving them a series of commands.		DotDash Blocky
Pattern Recognition	Observing patterns, trends and regularities in data (Google)			