Self-Study Journey from a Novice to an Expert for Computational Thinking Practices

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Abstract: This study details a researcher’s self-study journey in advancing from a computational thinking (CT) novice to an expert. The researcher went through a four-stage process, with a preliminary literature review preceding the four stages. From the literature review, the computational thinking analysis (CT_AT) tool was developed for use in stage one to analyze science, technology, engineering, art, and mathematic (STEAM) modules. Although no discernable patterns were found in analyzing the five science and five engineering-based modules, the analysis revealed which CT practices were missing or weakly exposed. In stage two activities were suggested to promote these missing or weakly exposed practices. Stage three required the researcher to develop his own STEAM module from the viewpoint of exposing students to CT. The fourth stage was to validate the CT_AT through interviews with pre-service and in-service teachers. These interviews led to changes in the CT_AT tool and, as a result, the researcher produced a guidebook that could be used by teachers in their own CT studies. This guidebook can be used by teachers to develop and become competent in CT skills.

Keywords: computational thinking, STEAM, teacher, self-study, guidebook

Introduction

Although not the first to use the term ‘computational thinking’, Wing released two highly influential articles (Wing, 2006; 2008) that elucidated CT with ‘The two A’s of Computational Thinking’, abstractions and automation. She describes abstractions as the mental tools, as the cognitive and intellective skills employed to understand problems and then deduce a process to find a solution to the problem. Automation is the second ‘A’ that Wing presented and she characterized this as metal tools. These metal tools are the devices that are used in the process of finding a solution. This can refer to real physical objects such as test tubes, scales, and voltmeters, but also to tools such as computer software and mathematical concepts. These are the tools that empower the solution of complex problems and the automation of finding those solutions.

Automation is mechanizing our abstractions, abstraction layers, and their relationships (Wing, 2008). Wing (2010) defines CT as a two-step process of abstracting a problem and then proceeding to computationally find a solution. Also finding CT to be a two-step process is the Royal Society (2012), “Computational thinking is the process of recognizing aspects of computation in the world that surrounds us, and applying tools and techniques from Computer Science to understand and reason about both natural and artificial systems and processes” (p. 29). Wing (2010) also explained how CT is an extension of the traditional definition of scientific literacy. The difference comes from the methods that might be used to find a solution, with CT emphasizing the possibility of using the metal tools to assist in the solving of the issue.

Moving on from the two-step process is the breakdown of CT by the second edition teacher resources for CT (ISTE & CSTA, 2011), which lists nine skills. The skills in the order presented by the teacher resources are Data Collection, the gathering of data either by the use of experimentation or searching already compiled data. The rest of the nine skills include Data analysis, Data representation, Problem decomposition, Abstraction, Algorithms and procedures,
Automation, Simulation, and Parallelization.

Weintrop et al. (2015) developed their taxonomy through five steps. The first step was a literature review that mainly focused on the meaning of CT from a scientific and mathematical viewpoint, but they also scrutinized computer science, engineering, and technology research. Two papers that started their investigation were by the National Research Council (NRC, 2010; 2011). Ten skills were set out following this step (Weintrop et al., 2017). The second step was to look at a program funded by the National Science Foundation called “Reach for the Stars”\(^1\). 208 instances of CT were found, but the researchers found that they were not all well represented by the 10 skills of the first stage. After the analysis the researchers expounded a list of 45 CT skills. The third step was a process of amalgamation of the 45 CT skills. This was done by the larger research group with the decisions being validated with graduates of the “Reach for the Stars” program and in-service teachers. The 45 skills were consolidated to a taxonomy of 27 skills in 5 categories. CT experts and STEM curriculum designers were also shown the taxonomy. They were of the opinion that some of the practices of the Problem-Solving category were not unique enough to STEM. After this feedback the taxonomy was 22 practices in 4 categories. The fifth and final step was to consult with STEM practitioners of many different disciplines, such as, biochemists, physicists, material engineers, astrophysicists, computer scientist, and biochemical engineers (Weintrop et al., 2015). The aim was to make sure that the taxonomy would accurately represented genuine scientific settings.

The result of the five steps was a taxonomy that consists of 22 practices arranged in 4 major categories. These major categories are titled, data practices, modeling and simulation practices, computational problem-solving practices, and systems thinking practices. The data practices category has 5 smaller components: collecting data, creating data, manipulating data, analyzing data, and visualizing data. The next category of modeling and simulation practices has 6 components: using computational models to understand a concept, using computational models to find and test solutions, assessing computational models, designing computational models, and constructing computational models. The third category, computational problem-solving practices has 7 components: preparing problems for computational solutions, programming, choosing effective computational tools, assessing different approaches/solutions to a problem, developing modular computational solutions, creating computational abstractions, and troubleshooting and debugging. The fourth major category, systems thinking practices has 5 components: investigating a complex system as a whole, understanding the relationships within a system, thinking in levels, communicating information about a system, and defining systems and managing complexity.

The popularity of CT, as being a part of curricula, has been increasing all around the world (Liu et al., 2011) and the benefits it would bring for students are clear (Park & Green, 2019). However, the effort required to achieve this is extensive and teachers will face many challenges (Bower et al., 2017). As (Peng et al., 2014) points out, they are always concerns about the number of qualified teachers whenever a new curriculum is proposed. With teachers also being concerned when asked to develop new teaching resources (Meerbaum-Salant et al., 2013). One of the first issues to consider must be to investigate the current state of knowledge about CT amongst teachers. Sands et al. (2018) attempted this with a study of 74 primary and secondary level teachers from Midwestern America. The teachers were surveyed on the phrase “Computational Thinking involves…..” (Sands et al., 2018, p.155). The ten phrases are ‘Computational thinking involves…’ solving problems, using heuristics/algorithm, logical thinking, thinking like a computer, coding/programming, doing mathematics, using computers (e.g. office tools), knowing how to use a computer, using technology in your teaching, and playing online games. The teachers’ answers were

\(^1\) https://gk12.ciera.northwestern.edu/
compared with the researchers’ opinions, formed by literature review. While there was some overlap, the teachers’ answers showed they have “incorrect ideas” about CT. “The results suggest that there is much work to be done before in-service teachers are able to implement computational thinking in their classrooms” (Sands et al. 2018).

There have been studies, such as, Bower et al., (2017), Blum & Cortina (2007), Yadav et al. (2011), Morreale et al. (2012), Vieira & Magana (2013), Yadav et al. (2014), and Curzon et al. (2014), which demonstrated that the workshops had a positive effect on the teachers’ knowledge of CT and how to teach it. As Lockwood & Mooney (2018) conclude the workshops mean that “…misconceptions and misunderstandings can be corrected…” (p. 33). The researcher’s self-study journey is similar in many ways to the processes that a teacher might undertake in the above-mentioned professional development programs. Before starting the journey the researcher had some misunderstandings and misconceptions about CT. However, through the different stages: literature review, analysis, and practical development, the researcher was able to correct these issues. While it might be impractical to have every preservice and inservice teacher go through the same extension study that the researcher did, the above studies have shown that with some professional development they can have the knowledge and confidence to include CT in their lessons.

The research question is how the researcher forms the understandings of computational thinking in practice as well as theory and what guideline can be developed for teachers to use to implement computational thinking practices into the learning context.

Methodology

Self-Study Journey

This paper details the researcher’s self-study journey from computational thinking (CT) novice to expert. The self-study consisted of four stages (Table 1) with a prerequisite literature review stage before the four stages. While the literature review looks at an extensive range of sources the main influences on the research came from Wing (Wing, 2006; 2008), ISTE & CSTA (ISTE & CSTA, 2011), and Weintrop (Weintrop et al., 2015) and Park (Park & Hwang, 2017; Park & Park, 2018, Park & Hwang, 2019). There is more information about the literature review in the ‘Introduction’ section. From this literature review the researcher developed the Computational Thinking Analyzing Tool (Table 2) (CT_AT) to evaluate STEAM modules for CT content. The reason why the researcher analyzed STEAM to see if any CT

<table>
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<tr>
<th>Table 1. Flowchart showing the stages of the researcher’s self-study journey</th>
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<td>Stage</td>
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| 1 | Analysis of 10 STEAM Modules | - Modules downloaded from KOFAC website based on content tag (science or engineering) and middle school level. Modules translated to English.  
- Some modules rejected based on their content or length.  
- Modules analyzed for CT practices using CT_AT, then the analysis discussed with supervisor.  
- Modules analyzed and discussed a total of three times. |
| 2 | Suggestions to Improve Missing or Weakly Exposed CT Practices | - Area that needs improvement decided upon for each module. Decision based on individual module analysis result and the results for all five science or engineering modules together.  
- An activity was suggested to improve either missing or weakly exposed CT practices for each of the ten STEAM modules analyzed for research question 1. |
| 3 | Developing a STEAM Module from Scratch to Expose Students to CT Practices | - Overall story and issue(s) of the module and lessons developed.  
- Activities can expose the students to CT practices sourced and modified from the internet.  
- The module was analyzed in the same way the ten STEAM modules from the KOFAC website were analyzed |
| 4 | Validating the CT_AT with Two participants (one preservice and one inservice teacher) | - Students shown diagrams to briefly explain the 16 CT practices of the CT_AT. Two participants then analyze two STEAM modules.  
- Informal discussion between participants and researcher of their feeling about the CT_AT.  
- Researcher explains the 16 CT practices in depth. Two participants analyze the two STEAM modules again.  
- How to improve the CT_AT discussed with the two participants and improvements implemented. |
practices would be found there is that the purpose of STEAM education and CT use are the same, equipping students/people with competencies to be creative problem solvers (Wing, 2006; 2008; Park & Park, 2018; Park & Green, 2000).

Stage one was an analysis of 10 STEAM modules, which were found on the KOFAC (Korean Foundation for the Advancement of Science and Creativity) website. Based on the researcher’s background and areas of interest it was decided to analyze modules that were either from a science or engineering basis and were aimed at the middle school level. After finding some modules that fit the requirements they were translated from Korean to English by the researcher. Some of the modules were rejected due to their length being either too long or too short. Some modules were also rejected on quality grounds. Once a decision of which five science and five engineering modules was made they were analyzed using the CT_AT. Each module was analyzed three times and after each time there were discussions with an expert in science education and CT to reach a consensus. This stage is to demonstrate that pre-service and in-service teachers can analyze their existing material to determine how exposed their students already are to CT practices and what areas need to be improved to more widely expose their students to the full range of CT practices.

Stage two was making suggestions on how to improve the missing or weakly exposed CT practices. Using the CT_AT analysis of the modules during stage one, the CT practices that are weakly exposed or missing for each module were scrutinized. The researcher then designed and suggested an activity that would introduce the weakly exposed or missing CT practice to the module. These suggestions took on two forms. One form was that the existing module’s activities were changed and expanded to offer the chance for the students to experience the CT practices. The other form was for the researcher to introduce new activities to the modules in order to expose the weakly exposed or missing CT practices. This stage is to demonstrate to pre-service and in-service teachers how it is possible to adapt their existing materials so as to expose their students to a greater range of CT practices and change activities to expose those students to CT practices that are missing or weakly exposed.

Stage three of the self-study journey was to develop a completely new module. The first step of this process was to decide the main theme of the module. Based on the researcher’s background of astrophysics it was decided to use the idea of visiting and living on another planet. There is also a need for STEAM programs to address an important societal issue, which in this case was decided to be climate change. It was then a case of designing the activities that the students would be presented with in the module. This was always done from the view point of exposing students to a range of CT practices. The module went through a range of drafts with activities changed, deleted or added to strengthen the CT exposure. Some of the activities were of the researcher’s own design, but many were sourced from the internet and then modified as references. After the module was finished it was analyzed with the CT_AT in the same way the ten STEAM modules of stage one were analyzed. The analysis was done to provide evidence of how the module exposes students to CT practices. This stage was to show how it is possible to develop new modules from the view point of having students experience the different CT practices. The researchers has intentions to develop STEAM programs with the purpose of including CT practices.

Stage four was to look to validate the CT_AT. Two pre-service and in-service teachers were chosen for their backgrounds in science, with both of them pursuing PhD degrees in science education. Both of them were familiar with STEAM programs, but not with CT at first. Another important factor was their ability to converse with the researcher in English but they did not have any problems in communicating in English. The pre-service and in-service teachers were first provided with diagrams giving some basic information about the 16 different CT practices present in the researcher’s CT_AT. This basic information was some hints and suggestions to
provide some context for what kind of activity would be considered that practice, how commonly the practice is found, and some things to watch out for when assigning the practices. The pre-service and in-service teachers then used this information to analyze one science-based STEAM module and one engineering based module. After this analysis the pre-service and in-service teachers and the researcher had an informal interview to hear their thoughts, feeling and opinions on doing the analysis. The researcher then presented the pre-service and in-service teachers an in-depth description of each CT practice and showed them examples of that practices from the ten STEAM modules analyzed in stage one. Using this new insight the pre-service and in-service teachers an in-depth description of each CT practice and showed them examples of that practices from the ten STEAM modules analyzed in stage one. Using this new insight the pre-service and in-service teachers then analyzed the modules again. After this second analysis the pre-service and in-service teachers and researcher met again and again discussed their thoughts, feelings and opinions. This time, however, the researcher also asked the pre-service and in-service teachers to explain why their analysis had changed. Based on these discussions the researcher produced a guidebook that could be used by pre-service and in-service teachers as part of their studies into CT.

### Results

#### Analysis of STEAM Programs to See if Any CT Can Be Included

After the ten STEAM modules there decided upon and translated from Korean to English they needed to be analyzed. Figure 1 below depicts an example of the collected data from one of the modules. The heading shows that this is an example of the second practice, Creating Data (DP2), of the major category of Data Practices (see Park & Green, 2020). The heading also shows that this example of DP2 was found in the fourth science module, which is titled ‘Silver Care Expert’. Next there is a screen shot of the activity directly taken from the module. With the CT practices highlighted with a black box. The box below the screen shot gives some context for where the activity can be found in the module and what the students are being asked to do in the activity. The final box in Fig. 1 gives some detail about the CT practice found in the screen shot and why it should be considered as an example of that CT practice.

While the individual modules did have uneven distributions of instances of CT (Park & Green, 2020)
between three major categories: data practices, modeling and simulation practices, and problem-solving practices, that unevenness is much reduced when looking at the combined results (Fig. 2). This shows that the discipline, science or engineering, is not an indication of what CT practices will be found.

The intention of the researcher is not to say that the modules are poor or insufficient as learning materials because the analysis shows missing or weakly exposed CT practices. It should also be noted that not every module has to expose students to every CT practice. Rather the researcher’s intention is to say that CT can be a useful vector for students to learn to be creative problem solvers (Park & Park, 2018; Wing, 2006; 2008; 2010). The results show that CT is a part of STEAM and that teachers can analyze their materials to ascertain what CT practices are present and to what extent.
Improvement of Weak CT and Development of Missing CT Components

The next stage of the results gives an example (Park & Green, 2020) of how the researcher efforts to improve the missing or weakly exposed CT practices in the existing STEAM module. In the example (Table 3) it can be observed how an additional activity was suggested that would promote the exposure of the CT practices: MS5, PS2, and PS6. These three practices were either missing (MS5 & PS2) or weakly exposed (PS6) in the original module.

To validate the changes and additions that the researcher made a sample of them were sent to two experts in STEAM and CT to survey them. The survey asked the experts’ opinion on how well the suggested activity promotes the CT practice. The results of the survey were generally positive and their opinions prompted some amendments to the activities. This way, the researcher constructed the validity by discussing with experts and suggesting some CT practices which could promote them to develop STEAM programs.

Table 3. The improvement of CT practices by adding the activity in science STEAM module

<table>
<thead>
<tr>
<th>Original Activity in the lesson</th>
<th>Suggested Additional Activity</th>
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<tr>
<td>★ Space weather forecast system</td>
<td>Let’s make an early warning system for space weather.</td>
</tr>
<tr>
<td>Let’s explore space weather center and space weather forecast service site and arrange solar observation information and meteorological factors</td>
<td>We will construct and program an Arduino to check the space weather website and provide a live RSS feed of space weather information.</td>
</tr>
<tr>
<td>1. Set-up the Arduino as follows: <strong>(MS5 skill added)</strong></td>
<td></td>
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<tr>
<td>2. You will need to import the Arduino and python code to your Arduino. The teacher will provide the codes for you. (They can also be found easily by searching the internet for “Arduino RSS feed project”: <strong>(PS2 skill added)</strong></td>
<td></td>
</tr>
<tr>
<td>3. If your RSS feed doesn’t work, check these 3 things to find the mistake. <strong>(PS6 skill added)</strong></td>
<td></td>
</tr>
<tr>
<td>a) Check the port in the python file. Your Arduino may be labeled differently or be numbered differently.</td>
<td></td>
</tr>
<tr>
<td>b) Check that the RSS feed doesn’t have a ~ in the data.</td>
<td></td>
</tr>
<tr>
<td>c) Try running the .py file from the command line as an administrator. Sometimes the script doesn’t have proper permissions to access the COM ports.</td>
<td></td>
</tr>
<tr>
<td>Arduino set-up and programming taken from <a href="https://www.instructables.com/id/Wiring-up-the-LCD-and-the-LED/">https://www.instructables.com/id/Wiring-up-the-LCD-and-the-LED/</a></td>
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CT practices improved in this module: MS5 + PS2 + PS6

The 3rd stage of the self-study journey was to develop a STEAM module from scratch to demonstrate the feasibility of developing STEAM materials from the view point of exposing students to CT practices. Due to the researcher’s background of astrophysics the theme of building a colony on Mars was used, with the idea of escaping climate change being used to drive the students’ interest. Figure 3 below shows one of the pages in the module developed by the researcher. The figure also shows the analysis by the researcher to show what CT practices can be found and a short description as to why the activity is that CT practice. The researcher could develop new STEAM modules with the intention to include CT after being trained to...
implement CT practices freely.

Figure 4 shows the results of the analysis of the researcher’s own developed STEAM module. When compared to the results for the 10 STEAM modules found on the KOFAC website (Park & Green, 2020) it can show that the researcher’s module exposes the students to a greater range of CT practices. In the researcher’s module the students would be exposed to almost all of the CT practices, with MS3 (Assessing Computational Models) being the only missing practice. There was no reason that this practice was not present in the researcher’s STEAM module, just that the activities made did not have it present. The researcher discussed with the expert if he should redo and modify the module to include MS3 which was not present in the newly developed STEAM module, which is how to construct the validity in developing STEAM module with CT practices inclusion. This, however, was deemed unnecessary as MS3 is the joint 3rd most common skill found in the five science modules in the earlier study (Fig. 2). Therefore, while the students don’t have the chance to experience MS3 in the researcher’s module it is likely that they would be exposed while working on another module. It had also been demonstrated during the second stage of the self-study that an addition activity could have been developed if the exposure to the full range of CT practices was required.

The researcher found very few difficulties in designing the module. The majority of difficulties that the researcher did encounter were difficulties that every course designer would encounter, overall thematic decisions. After the overall thematic decisions were made it was not difficult to find activities that fit the requirements of exposing the students to CT practices. This is because new activities don’t need to be designed just to include CT practices. CT practices can be found in classic and existing activities. Therefore, with minimum issues teachers and course designers can find activities that fit with their overall thematic decisions and exposes the students to CT practices.

Fig. 4. The pattern of CT practices found in the researcher’s developed STEAM module
Construct the Validity of CT Tool through Two Teachers’ Self-Study

The fourth stage of the self-study journey involves the discussions between the researcher and the pre-service and in-service teachers. All conversations and interviews with the pre-service and in-service teachers were one-on-one so that the results had no contamination between the views of each pre-service and in-service teacher. There are two parts to this stage. For the first part the pre-service and in-service teachers were presented with a basic definition of the 16 different CT practices present in the CT_AT. They were then given two of the STEAM modules that the researcher analyzed in the first stage of the self-study journey. They were given Science 4: ‘Silver Care Expert’, and Engineering 1: ‘Create Automated Devices for Safe Living from Disasters’. Based on the researcher’s analysis these two modules demonstrated the greatest range of instances of CT practices. So they were chosen so as to give the pre-service and in-service teachers the opportunity to experience as many CT practices as possible. Following the pre-service and in-service teachers’ analysis, there was a meeting with the researcher. The purpose of the meeting was to hear the pre-service and in-service teachers’ thoughts and opinions about doing the analysis of the modules. The following are the two participants’ thoughts in no particular order.

- Not easy to analyze a module but not too difficult.
- It is difficult to understand how DP2 is different to DP1. What action is different between collecting the data and creating the data?
- It is difficult to understand what DP3 is.
- Having the practices number 1-5 led to thinking it was a step process.
- From Science 4: Students are making a webtoon activity. What is the difference between model and tool? Not sure how to separate MS3 and PS3.
- MS5: Is it making a result or making a model. Students are making a cartoon. That isn’t a model, it is a result. Student doesn’t know if that is MS5 or not.
- Students are thinking about their cartoons, is that MS4? Cartoon is not a model. Cartoon is a tool not model.
- What is the difference between PS1 and PS5? What is the difference between decomposition and abstraction? Are they the same thing? How do they differ? Breaking into smaller parts is the same as deciding what the important/unimportant factors are.
- MS4 and PS2 are the same? Designing the model process (MS4) is the same as algorithm (PS2).
- If the students are just thinking of ideas is that DP2. Not sure what practice is should be.

After this discussion with the pre-service and in-service teachers, the researcher presented them a table that provided a detailed definition of each CT practice and an example of an activity that would be considered that CT practice. The participants were then asked to analyze the same two modules again and the pre-service and in-service teachers were met again to discuss their thoughts and opinions. The following is some of the participants’ thoughts and opinion, presented in no particular order.

- I was much “stricter” in assigning practices this time. I think the activities should exactly fit the definitions outlined by the researcher.
- My first analysis I feeling like I only really understand the data practices. So first time I over-subscribed those.
- I hadn’t considered algorithms to be a form of programming. I thought that was only about using a computer.
- I hadn’t thought about PS1 (Preparing Problems for Computational Solutions) being decomposition in my first analysis.
- I thought the same about PS5 (Creating Computational Abstractions) and abstraction. I know the terms decomposition and abstraction from my studies, but I had not associated them with CT.
- It was difficult to differentiate between decomposition and abstraction. The book definitions of the two are not difficult to distinguish, but I found it difficult in practice.
Table 4. Guidebook entry for the DP2 (Creating Data) practice (example)

Creating Data (DP2)

Definition
This practice is the generation of data when the phenomena cannot be observed of measured easily. Some examples of how a student would demonstrate this practice would be:

- Create a computer program to generate data of a phenomena that cannot be observed experimentally, i.e. evolution of a species, the interior of a star.
- Students record their own thoughts and opinions.

What is New for Computational Thinking with This Practice?
The use of computers allows for the use of computer simulations to be run that can produce the data required. The students input the formulas and variables into the computer program, which then runs the calculations and outputs the results. Without a computer it would take a prohibitively long time to manually calculate the results.

Example of This Practice’s Use
The following example is from a science module about the issues and difficulties that elderly people face in their daily lives and the impact that has on society and future occupations. The students also learn about different pieces of technology and how they can be used to help elderly people.

This activity is at the start of lesson 1. In lesson 1 the students learn about the issues that elderly people have and discuss about the aging society and possible jobs of the future. They also do a survey to ask elderly people about their issues put the results into graphs.

* Write five words that come to mind when you are my grandmother or grandfather
* Write down what you think is difficult about your grandmother and grandfather’s economic, physical, and surrounding circumstances.

In the first part of the activity, the students need to write down five words that come to mind when thinking about their grandparents. In the second part of the activity the students are considering the economic, physical, and environmental surrounding difficulties of elderly people. This activity is considered as DP2 because the students are creating the data to be used in a survey.

An Example of Activity That Could Be Confused for This Practice
The above example is from an engineering module where the students are looking at natural and man-made disasters and how technology could be used to make warning device for disasters. The above example can be found towards the middle of the third lesson of the module, but it is the starting activity of the students developing their own warning device for a natural or man-made disaster.

This activity could be confused as being ‘Creating Data (DP2)’ as the students are being asked to create questions for the survey. However, the creation of the questions is not the main point of the activity. The main point of the activity is using the questions to ask people for their thoughts and opinions on disasters. As the students are asking other people the data is coming from an outside source, and it is therefore ‘Collecting Data (DP1)’.

Where This Practice is Commonly Found in Lessons and Modules
This question is not easy to answer for this particular practice. This practice is not that commonly found and therefore the data concerning where it is found is not very extensive. The majority of the researcher’s experience with this practice was at the beginning of activities, but not necessarily the beginning of lessons or modules. It was commonly used as a way to get students thinking about possible issues and their solutions, before an activity where the students are developing something to do with their proposed solution.

In their study the researcher never found an activity where the students were running a computer simulation to generate data for an unobservable phenomenon. This may be due to the study’s concentration on the middle school level, and that the running of a computer simulation is seen as inappropriate for middle school. Further study of high school and college level modules is needed.

Final Thoughts
This practice was not commonly found in the study. This practice is to be found when the data is being generated by the students themselves, either by running their own computer program or from their thoughts and opinions.
Table 5. Guidebook entry for the MS5 (Constructing Computational Models) practice

Constructing Computational Models (MS5)

**Definition**
Can be the generation of new models or the adjustment of an existing model. This practice is the actual implementation of the design choices. Some examples of how a student would demonstrate this practice would be:

- After designing the photo bioreactor this would be the actual construction of the reactor. Such as building the circular reactor and placing the hexagonal mirrors around it. Putting the algae in the reactor and setting up an Arduino to monitor the algae for the optimum time to harvest.

**What is New for Computational Thinking with This Practice?**
There is not a change in the fundamental nature of this practice with the advent of CT. The difference now being that the construction of the model may be on the computer rather than a physical model.

**Example of This Practice’s Use**
The following example is from a science module about the island of Dokdo. The students learn about how Dokdo was formed, the different types of rock, and what rocks can be found on Dokdo.

This is the last activity of lesson 2. The lesson is about the appearance of Dokdo. In this activity the students are creating a 3D map of Dokdo Island. The students construct the model by cutting out the layers and then sticking them together to build up the complete model. This is considered to be MS5 as the students are physically constructing the model.
The researcher with two participants had a fruitful discussion about the analysis of one in the activities in the module. The participants had judged it to be an example of DP4 (Analyzing Data), but the researcher considered it to be PS5 (Creating Computational Abstractions). Each side presented their opinions with the pre-service and in-service teacher emphasizing the data analysis part of the activity and the researcher emphasizing the part of the activity where the students are deciding what data is the most important.

These discussions with the pre-service and in-service teachers lead the researcher to some changes to the CT_AT. The practice PS1 was changed from ‘Preparing Problems for Computational Solutions’ to ‘Decomposing Problems to Allow for a Computational Solution’ and PS2 was changed from ‘Programming’ to ‘Programming and Algorithms’. These changes were made to make it easier to understand for students studying CT. The discussions also highlighted the need for some material that people studying CT could use to help themselves on their journey.

Following the discussions with the pre-service and
in-service teachers, the two researchers met to examine the best method and what to produce that could be used to help people studying CT. It was decided to produce a set of guidelines that could be used as reference.

**CT Guidebook for Teachers’ Self PDP (Professional Development Program)**

The guidebook takes the learner through the sixteen CT practices found in the CT_AT, providing the reader with a definition, how CT might have changed this practice, an example activity where the students are strongly exposed, an example of an activity that could be confused for this practice, where the practice is commonly found in modules, and finally some thoughts and opinions the researchers had on their self-study journey. To demonstrate the usefulness of the guidebook for pre-service and in-service teachers the entries for two CT practices are shown. Table 4 shows an example of the researchers’ guidebook entry for DP2 (Creating Data) and Table 5 gives the entry for MS5 (Constructing Computational Models).

**Conclusion and Implication**

In this paper the self-study journey of the researcher in their preliminary investigation of computational thinking was presented. The journey was a four-stage process with a pre-stage literate review and the conclusions are as following with implications.

Firstly, CT practices can be included and implemented in STEAM programs with the intention of equipping students with the competencies of CT practices. In stage one of the self-study the CT_AT was used to analyze 5 science-based and 5 engineering-based STEAM modules from the KOFAC website. The results imply that there are instances of CT present in STEAM modules even though the STEAM modules were not developed at first with the intention of including CT inside. The purpose of STEAM education and CT practices in any discipline are the same, to equip students with competencies to be creative problem solvers. However, the sixteen CT practices are not all present to the same extent. Teachers can use the CT_AT to analyze their teaching materials so that they have the information available about any practice that they are wanting the students to experience, but is missing or weakly exposed. The second stage was to develop activities for the modules to promote missing or weakly exposed CT practices. The results of stage two imply that it is possible for teachers and course creators to develop activities if they find that their material is not giving the chances for students to experience the CT practices that they wish. The third stage was to design and create a new STEAM module from scratch. The result implies that competence in the practices of CT can give teachers the self-confidence to develop their own materials. Stage four was to validate the CT_AT with interviews and discussions with two pre-service and in-service teachers. The discussion led to some changes in the CT_AT, such as changing PS1 from ‘Preparing Problems for Computational Solutions’ to ‘Decomposing Problems to Allow for a Computational Solution’, and PS2 from ‘programming’ to ‘programming and algorithms. The discussion also led the researcher to the need to produce a computational thinking guidebook to help guide learners in their studies into CT.

Secondly, teachers need to understand CT in practices as well as theories through professional development program (PDP) even though it is a type of self-study. Pre-service and in-service teachers in this study are guaranteed to be able to use this self-study journey in their own journeys of discovery, so that they can utilize CT in their classrooms to the benefit of their students. The teachers can reference the guidebook developed in this study when they are experiencing confusing. If they are baffled by the taxonomy then they can consult the definition section of the guidebook. If they are not sure which CT practice a particular activity is, then they can compare the activity to the example activities in the guidebook. PDP is very necessary for teachers to keep developing and improve the competency of CT practices. Teachers can follow this preliminary self-study of CT.
to gain the self-confidence to be able to identify CT practices, as well as, adapt and develop new activities to expose their students to CT. At least, the results of how the researcher changed from novice to expert in understanding and implementing CT practices can conclude that teachers in learning new competencies need to understand it in theories fully and implement it into the classroom practically, which takes a long time as PDP. The systematically developed PDP could guarantee teachers’ expertise in their teaching.

Finally, this study could revise the CT_AT to be used as a frame to produce a guidebook of CT practices. The CT guidebook includes the categories with CT practices, their definitions, and examples from STEAM programs. The CT guidebook can be used by current teachers who need to know CT in the classroom and for preservice teachers to use it to make lesson plans during their curriculum program. This guidebook can provide teachers and science educators the basic information and data so that they can be familiar with CT practices which are emphasized in science curriculum of 21st century (MOE, 2015; NGSS, 2012; NGSS Lead States, 2013).

Further research is needed to increase the validity of the CT_AT and the guidebook. Discussions with pre-service and in-service teachers are needed to reach consensus of opinion for both the CT_AT and the guidebook, so that the usefulness of both can be maximized in helping others in their pursuit of CT knowledge. The need and role of CT’s place in the classroom has been extensively put forward in theory, but there is still work to be done so that teachers have the knowledge and self-confidence to use CT in their classroom practically. This study was an exploratory step towards practical use of CT, but more steps are needed.

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