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박사학위 논문

Exploring the development of computational thinking practices guidelines and its implication applicable in STEAM lessons

STEAM 수업에 적용 가능한 컴퓨팅 사고 실천 가이드 개발 및 제언 탐색

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Abstract

The term computational thinking (CT after this) has been around for a long time, mentioned at least as far back as the 1960s. The term has been widely cited by Jeannette Wing and an extensive discussion has continued (Nardelli, 2019) with Wing's work and research at the National Science Foundation. So far, however, the narrative for CT has been mainly based around computer science despite Wing's assertions that CT plays a role in other disciplines (Wing, 2006). In this paper it will be shown that CT is a necessary skill to be taught in science education.

This paper has been written to answer four research questions. First, based on learnt knowledge, what kinds of CT practices can be found in STEAM programs and what description of CT in STEAM can be illustrated? This first question is also extended to determine whether there a difference can illustrated between five science focused STEAM programs, and five engineering focused STEAM programs. The second research question is, through continued professional development, what additional or extended CT practices can be suggested to revitalize STEAM programs on the basis of the descriptions made above? The third research question, is after coming towards the end of self-study journey, what difficulties are encountered when developing a new STEAM module from the viewpoint of exposing the students to CT practices? Therefore, demonstrating that teachers and course creators can also be trained to design STEAM modules with the aim of giving students the opportunities to experience CT practices. Finally, the fourth research question is from the experience gathered during the self-study how can the researcher develop a professional development program to aid pre-service and in-service teachers' in their own journey to study computational thinking?

The STEAM programs were chosen from the KOFAC (Korean Foundation for the Advancement of Science and Creativity). Programs with more science content, were designated as a science-focus

STEAM program. If there is more engineering content, this is an engineering-focus STEAM program. Two frames were mainly used to produce one reasonable CT analyzing tool frame in this study; one is from Park & Hwang (2017) and the other is from Weintrop et al. (2015). The researcher compared those two frames (Park & Hwang, 2017; Weintrop et al., 2015), combined, modified, and redefine CT practices/protocols with examples. Major categories in CT were from the Weintrop et al (2015) frame and sub practices were compared and finalized with an operational definition. The modified CT_AT (Computational Thinking Analyzing Tool) includes 5 protocols in Data Practice (DP), another 5 in Modeling and Simulation Practice (MS), and another 6 in Computational Problem Solving Practice (PS).

To answer the first research question the STEAM programs were analyzed with the CT_AT tool. The analysis of the five science focused STEAM programs showed that of the 16 CT practices only 2 registered zero instances. The two absent practices were 'Using Computational Models to Find and Test Solutions' (MS2), and 'Programming' (PS2). The results also show that the found practices are distributed between the three major categories with the follow percentages. 'Data practices' accounted for 33.1%, 'modelling and simulation practices' represented 28.2%, and 'computational problem solving practices' 38.7%. This shows that the CT practices found in science focused STEAM programs are not limited to only one category. For the five engineering focused programs there was only 1 completely absent practice, 'Creating Data' (DP2). The practices were less evenly distributed than the science programs. For the engineering programs 'data practices' accounted for 28.3%, 'modelling and simulation practices' represented 23.2%, and 'computational problem solving practices' 48.5%. Therefore, the research shows that the STEAM discipline does not determine what CT practices the students will be exposed to, but rather the activities the program developer created for the program.

To demonstrate what kinds of CT practices can be suggested to revitalize STEAM programs to enhance weakly exposed or missing CT practices, and answer the second research question, suggestions were made. The researcher took the STEAM programs analyzed for research question 1 and recommended additional or adapted activities so that the students would be exposed to a wider range of CT practices. The researcher was able to propose an additional or modified activity for each module. These additional or modified activities introduced weakly exposed or missing practices. The ability to do this for each module without fail shows that it is possible for teachers and course creators to take existing programs and adapt them to include any CT practices that they require.

To answer the third research question the researcher devised their own STEAM module, created from the ground up, with the aim of exposing the students to CT practices. After completion of the design phase the program was analyzed under the same process the ten STEAM programs were analyzed for research question 1. The results showed a program with only one missing CT practice 'assessing computational models' (MS3). When studying the individual results for the ten STEAM modules the lowest number of missing practices was 3, for both Science 4 and Engineering 1. The module with the greatest number of missing practices was Science 5 with 10 absent practices. The average number of missing practices for the 10 programs downloaded from the KOFAC website was 6.1. The designed program was, therefore, successful in demonstrating the feasibility for teachers and course content creators to produce STEAM programs from a CT viewpoint.

To answer the fourth research question the researcher asked two students to use the CT_AT to analyze two STEAM modules. There were three stages to this analysis. The first stage was the students analyzing the modules with minimal input from the researcher. The students were given diagrams with the names of the practices and basic information. The researcher then went through the researcher's definitions of the CT practices and examples of their use. After each analysis the researcher and students met and discussions were had to reach a consensus of opinion on the CT practices. These discussions were very useful for both the researcher and the students to further their knowledge of CT and some good suggestions were made about how the CT_AT could be improved. It is hoped that the CT_AT could in the future be used as part of a professional development program.

The final conclusion of this dissertation is the result of the researcher's journey of self-study. When the researcher started his journey he did not have much knowledge about CT. However, through the literature review and putting ideas into practice by analyzing STEAM programs, suggesting enhancements to revitalize CT practice in those STEAM programs, and developing his own module with an emphasis on CT, the researcher changed and his knowledge grew. The forming of new concepts, connecting theory with practice, and employing that practice was development training for the researcher. With the need for teachers to increase their knowledge levels with regards to CT, it is hoped that teachers can use this dissertation as part of their professional development and follow the researcher's journey from CT novice to CT expert. To aid teachers in their study of CT the researcher made a guideline book (appendix) that could be used by teachers to increase their knowledge of CT and how to apply it is their classroom.

초록

컴퓨팅 사고 (computational thinking; 이하 CT)는 최소한 1960년대부터 꾸준히 언급되어 왔으며. 특히 컴퓨터 공학자인 Jeannette Wing에 의해서 최근에는 활발한 연구와 토론이 이어져 왔다 (Nardelli, 2019). 모든 영역에서 CT가 중요한 역할을 한다는 주장에도 불구하고 CT에 대한 연구는 대체적으로 컴퓨터과학이나 공학에 한정되어온 것은 사실이다 (Wing, 2006). 이 연구에서는 과학교육에서는 CT가 어떻게 활용될 수 있는지를 탐색하고자 한다.

이 연구에서의 연구문제는 다음과 같다: 첫 번째 CT에 대해 학습을 하고 형성된 관점으로 기존의 STEAM 프로그램에 CT 요소가 반영되어 있는지, 얼마나 반영되어 있는지 본 연구자가 기존의 CT 분석틀을 수정하여 완성된 CT_AT (컴퓨팅 사고 분석도구)을 이용하여 분석할 것이다. 이는 STEAM 교육의 목적이 4차산업혁명시대에 필요한 융합적인 사고를 할 수 있는 창의적 문제해결을 할 수 있는 사람이며 이는 곧 CT 사용의 목적과 일치하기 때문이다. 이를 위해서 기존의 한국과학창의재단에서 개발한 STEAM 교육 사이트에서 과학내용중심 5개의 STEAM 프로그램과 공학중심 5개의 프로그램을 대상으로 하여 분석하였다. 이는 본 연구자의 배경에 적절하고 중등수준의 프로그램을 선정하였다. 두 번째 연구문제는 앞서 분석한 CT 결과를 중심으로 잘 드러나지 않거나 제한적으로 나타나는 CT에 대해서 각 프로그램에 보강을 해보는 것이다. 이를 함으로써 본 연구자는 각 프로그램에 강하게 또는 약하게 나타나는 CT 실천에 대해서 처방을 내릴 수 있고, 어떻게 하면 제한적으로 나타나는 CT 요소에 대해서는 과학교육자로서 그 항목을 부각시켜 프로그램에 반영하거나 학생들에게 기회를 줄 수 있는지에 대한 가능성을 볼 수 있는 것이다. 세 번째 연구문제는 앞서 CT 분석과 보강할 수 있는 역량을 바탕으로 하여 본 연구자가 실질적인 4차시로 구성된 1개의 STEAM 모듈을 개발해 보는 것이다. STEAM 개발자로서 처음부터 CT를 염두해두고 CT가 반영된 STEAM를 개발해보는 것이다. 이는 이제까지 과학교사가 T와 E를 어떻게 반영해야 하는지에 고군분투한 점에 해결책을 제시한다는 점에서 의미가 있다. 본 연구자의 경험은 마지막

연구문제인 어떻게 하면 CT에 대해서 초보적인 역량을 지닌 교사가 CT에 대한 강한 이해 아래 프로그램 개발이나 수업을 할 수 있는 전문적인 역량을 함양할 수 있는지 자기연구(self-study) 방법을 적용하여 과학교육자로서 탐구 및 성찰을 중심으로 하여 CT 자기주도적 가이드라인을 (CT self-guideline) 개발하였다. 이는 앞으로 CT에 대해서 전문역량이 필요한 교사들에게 연수목적으로 사용될 수 있을 것이다.

이 연구를 위해서 한국과학창의재단의 공식적으로 개설된 STEAM 교육 사이트에서 과학중심의 중등용 5개의 STEAM 프로그램과 공학중심의 중등용 5개의 STEAM 프로그램을 선정하였다. 선정과정은 본 연구자의 배경에 맞추어서 선정한 것을 내용을 검토하여 이 연구의 목적에 적절한지를 과학교육 전문가와 의논하여 선정하였다. 또한 분석을 위해서 기존의 두 개의 CT 틀(Park & Hwang, 2017; Weintrop et al., 2015)을 토대로 과학교육전문가와 이 연구에서 사용할 CT 분석도구를 각각 요소에 적절한 보기와 함께 완성하였다. 주요 CT 실천영역은 Weintrop et al.(2015)에서 추출하였지만 조작적 정의를 확립하면서 구체적인 요소와 내용은 차별화되었다. 이 연구에서 사용되는 CT_AT는 3개의 CT실천으로 자료실천(DP)에 3개의 요소, 모델링과 시뮬레이션 실천(MS)에는 5개의 요소, 그리고 문제해결실천(PS)에는 6개의 요소가 포함되어 있다.

첫 번째, CT_AT를 이용하여 분석한 5개의 과학중심 STEAM 프로그램에는 CT 16개의 요소 중에서 2개만(MS2, PS2) 제외하고 3개의 CT실천에 14개 요소가 골고루 나타나는 것을 볼 수 있다. 즉 한 CT 실천에 제한적으로 나타나지 않음을 보여준다. 5개의 공학중심 STEAM 프로그램을 분석한 결과 통합적으로 본다면 한 개의(DP2) 요소만 빼고 역시 전체적으로 15개의 CT 요소가 골고루 포함되어 있으나, 과학중심의 CT 실천보다 공학중심의 STEAM 프로그램에서 문제해결실천 CT가 빈도면에서 덜 반영되어 있는 것으로 나타났다. 결국엔 학문의 다른 영역이 다른 CT 실천반영을 결정하는 것 보다는 프로그램에 나타나는 활동의 종류에 따라 CT 요소나 회수가 결정된다고 할 수 있겠다.

두 번째, 앞서 분석된 CT 반영정도의 결과를 바탕으로 약하게 포함되었거나 아예 나타나지 않는 CT요소를 보

강하거나 그 프로그램을 좀 더 CT가 강하게 나타나는 STEAM program으로 활성화 할 수 있냐는 문제이다. 이를 위해서 본 연구자는 본인의 CT에 대한 이해를 바탕으로 하여 각 과학 중점 또는 공학 중점 STEAM 프로그램에서 CT 요소를 더욱 보강할 수 있는 실질적인 활동내용을 추가하거나 수정하였다. 본 연구자는 CT에 대한 충분한 이해는 전문적인 실천지식으로 작용하게 되고 이는 곧 구체적인 교수전략과 연결되는 활동을 개발하는 것이 가능함을 보여주었다. 즉 약하게 나타나는 CT에 대해서 어디에서 관련 CT를 보강하여 활동을 추가하거나 수정할 수 있는지 보여주었다.

세 번째. CT에 대한 이론과 실천을 바탕으로 한 개의 4차시 모듈을 개발하였다. 처음부터 16개의 CT 요소를 골고루 포함하려는 의도를 가지고 천체물리내용으로 학습자들이 최대한 다양한 CT요소를 경험할 수 있도록 활동을 창작하고 모듈을 개발하였다. 개발 후에 이 프로그램을 분석한 결과 3개의 CT 실천영역에서 하위 16개의 CT 요소 중 한 개의 CT 요소가 나타나지 않았다. 이는 기존의 STEAM 프로그램을 분석하였을 때 4번째 과학 그리고 첫 번째 공학에서 CT 반영정도가 가장 많이 되어도 나타나지 않은 CT 요소가 3개였는데 본 연구자가 개발한 모듈의 경우는 1개만 나타난 것을 극히 CT 요소를 잘 반영하여 모듈을 개발하였다고 말할 수 있다.

마지막으로 4번째 연구문제에 대해서는 CT 실천에 대해서 교사들이 이해하고 이를 활용할 수 있는 연수용 가이드북을 개발하는 것이다. 본 연구자의 경험을 두 명의 예비교사들이 같은 경험을 하는 것이다. 즉 참여자에게 CT 실천관련 기본적인 정보를 주고, 자기주도적으로 CT의 정의 및 사례를 들어 CT에 대해서 알아가는 과정을 주는 것이다. 참여자 두 명은 본 연구자가 했던 분석 중 몇가지를 경험하고 일치하지 않은 분석결과에 대해서는 연구자와 의논하여 일치된 의견을 보여주도록 하였다. 이러한 분석의 결과를 의견일치하는 동안의 토론과정은 본 연구자로 하여금 교사들이 경험할 수 있는 CT를 이해하는 과정에서 생길 수 있는 모호한 점을 수정하거나 명확하게 하여 CT 실천 가이드북을 개발하는 데 사용되었다. 이는 CT 관련 교사연수프로그램을 위해서 사용할 수 있을 것으로 보인다.

자기연구(Self-study)방법을 적용한 이 연구는 다음과 같은 결론과 제언을 제공할 수 있다. 본 연구자는 CT에 대한 풍부한 이해를 가지고 이 연구를 시작하지 않았었다. 하지만 충분한 CT 관련 이론적 배경을 중심으로 하여 CT 대한 개념을 형성하고 이를 적용하여 기존의 STEAM 프로그램을 통해 CT 반영정도를 분석하고, 제한적으로 반영되는 CT실천에 대해서는 보강할 수 있었고, 이러한 CT 관련 이론과 실천을 중심으로 다양한 CT 실천을 포함할 수 있는 4차시의 한 개의 STEAM 프로그램을 개발할 수 있었다. 이러한 과정은 본 연구자를 CT 실천 활용 초보자에서 CT 전문가로 변화되는 과정을 보여주었고 이러한 과정을 토대로 교사교육에 활용할 수 있는 CT 실천 가이드북을 연구자는 개발할 수 있었음을 보여주었다. 성공적인 교사연수프로그램을 위해서 개발한 CT 가이드북은 그러한 과정을 포함하는 자료이기에 앞으로 CT 관련 교사전문성 연수자료로 활용될 수 있음을 시사한다.

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Chapter 1: Introduction

The purpose of science education is to furnish learners with the competencies to allow them to decide whether decisions faced in their everyday lives are right or wrong (MOE, 2015; NRC, 2012; Park, 2010). To make these decisions, learners should be able to diagnose the issue, describe the process logically, advance a claim based on experimental evidence, and evaluate their decisions ethically. These skills are called 'scientific literacy'. We must be sure that students have the necessary skills to form workable solutions to issues and problems (NGSS Lead States, 2013; Park, and Park, 2018a). To obtain this goal of scientific literacy students are taught science as inquiry (Hannasari, Harahap and Sinulingga, 2017; NRC, 2000; Park, 2010).

The term 'Contents-ON' is used when students learn concepts, and 'Hands-ON' is when students collect data through experimentation to demonstrate phenomenon. 'Minds-ON' is when students can form an argument to support their claims. If a science class is promoting only Hands-ON without Minds-ON then the students are merely following a process and are not being scientifically literate (Park and Green, 2019). Students, therefore, need to be equipped with both procedural skills and thinking skills (NRC, 2000; Park, 2010). This is called 'scientific thinking' and consists of first logical thinking and then critical thinking (Kuhn, 1993; Osborne et al., 2010; Park, 2010). An example of these skills can be seen in a climate change STEAM program developed by Park (2013). In this program the students had to decide what data to collect to ascertain if the climate is changing. Internet data was collected from the Korean Atmospheric Science Research Center to be used as evidence for the fact that there is climate change in Korea. Furthermore, the students developed an experiment to determine what the greenhouse effect is and which gas is the main contributor to global warming. The experiment involved seeing how three different materials, black paper, black plastic, and black film affected temperature. Students demonstrated several skills in the experiment, collection of data, discerning evidence from the data, and the use of evidence to bolster their claims. By supporting their claims with evidence the students demonstrated logical thinking. Also by assessing the other groups' evidence and claims they showed the critical thinking skill. First, came logical thinking and then came critical thinking, which is called 'scientific thinking' (Kuhn, 1986; Park, 2006; 2010). The thinking skills occur when students forge new concepts and obtain new knowledge from the starting point of their curiosity.

In the 21st century, however, the purpose of science education has expand in it meaning. Students need to go further than just acquiring new concepts and knowledge on the basis of their curiosity. They need to be given the skills to solve the problems and issues of the community. This competency of science education is considered as computational thinking (CT) (Lamprou & Repenning, 2018; Park & Green, 2019; Sengupta et al., 2012). CT is not new and there is extensive research and debate in the computer science and technology education community about CT (ISTE & CSTA, 2011; NRC, 2010; 2011, Wing 2006; 2008). In the computer science community CT consists of the following practices; problem representation, abstraction, decomposition, simulation, verification, and prediction. Wing (2006; 2008) argues that CT is a basic skill for all humans, not just computer scientists and she also addresses that CT should be taught everywhere including schools. Nine different skills of CT, defined by computer related associations (ISTE & CSTA, 2011), have been emphasized to be mastered by students at schools. These nine different skills are data collection, data analysis, data representation, problem decomposition, abstraction, algorithms and procedures, automation, simulation, and parallelization.

Recently, there has been a lot research and study about how to apply CT to the domain of science education. Next Generation Science Standards (NGSS) places a new emphasis on authentic scientific investigation with 8 distinct practices (NGSS Lead States, 2013). Computational thinking as the 5th practice (with mathematical thinking) is not familiar even to veteran teachers (Weintrop et al., 2015; Park

& Green, 2019). The inclusion of CT in the list of 8 practices reflects the growing importance of computation and digital technologies over the scientific disciplines. However, even with the inclusion of this practice, there is little information and guidelines for teachers who need to understand what CT is and how to apply it in the classroom. To fill this gap and connect the perception of computational thinking from technology to science education, there have been trials in research as follows.

Weintrop et al (2015) addressed this need by considering the practices of CT from the perspective of technology and transferred them to science education. They implied that people in science education will feel more comfortable in including CT into NGSS by using their developed taxonomy. If teachers do feel more comfortable in teaching CT, then policy-makers can prioritize CT as a part of science education and curriculum developers can produce CT materials targeted for science classrooms.

Park & Green (2020) address that CT is a critical practice if students need to be equipped with the competencies to be problem solvers for the 21st century. For scientific literacy, students need to have a chance to apply scientific concepts after forming them. Students form concepts by abstracting the problems they face. Students then apply those concepts to their daily lives by automating the solutions. The researchers also stated that CT can be observable and measurable by comparing and introducing CT components/practices and CT can be the catalyst for STEAM education. Sengupta et al (2012) agreed that CT is phrased to indicate a thought process involved in formulating problems and their solutions so that the solutions are represented in a concrete form to be carried out by an information-processing agent (Wing, 2006). CT becomes evidenced only in particular forms of epistemic practice involving the generalization or use of external representations.

Barr & Stephenson (2011) released that there are surely multiple definitions of CT in different disciplines and it is imperative to create a definition for CT in K-12 by considering the following; what

CT looks like in the classroom, what skills students would demonstrate, what teachers need in order to put CT into practice, and what teachers already do that could be modified and extended. To make this definition useful in the classroom, definitions with concrete examples demonstrating how CT can be incorporated in the classroom are needed. This self-study is an attempt by the researcher to provide teachers with the definitions and examples they need.

In considering CT concepts from a science education viewpoint there are several CT concepts that can be analogous to scientific concepts. Some examples of this are; collecting data from an experiment (science) from data collection (CT), summarizing data from an experiment (science) from data representation and analysis (CT), building a model of a physical entity (science) from abstraction (CT), and experimental procedure (science) from algorithms & procedure (CT). A few CT concepts like automation and parallelization were not matched directly with science practices appropriately but it is meaningful to try to make links between CT and other disciplines (computer science, math, science, social studies, and language art).

CT cannot be taught in a traditional way and has to overcome both pedagogical and systemic challenges (Lamprou & Repenning, 2018; Park & Green, 2019). More concrete descriptions and connections between CT and science can be explored on the basis of discussions and theories about CT. An example of student demonstrating the simulation skill is when high school students use an interactive simulation to explore the relationship between macroscopic properties of gases-pressure, volume, and temperature to see how these properties emerge from microscopic interactions. Simulation can be used as a tool to help students build conceptual understandings of the concepts being modeled, which is described as 'using computational models to understand a concept' in Weintrop et al. (2015) CT taxonomy. Park & Hwang (2017) worked with one teacher, Mr. Son, and he revised the curriculum to give students (6^{th} grade) the chance of building and reproducing a traditional Korean village with the function of reducing roof angles depending on the incidence of sunlight during different seasons. Mr. Son encouraged students to work on building algorithms with critical points to be considered. Students needed to calculate the exact angle of the roof according to the Sun's altitude at different seasons. This process was described as automation (Lamprou & Repenning, 2018).

There has been also connections between CT and STEAM programs and research reports that CT is a catalyst for STEAM programs. The integrating CT with STEAM is effective, and it provides a justification for the choice of programming in order to facilitate scientific modeling with CT. In most science textbooks, the curriculum indicates what to learn with the focus of scientific thinking. However if teachers revise the curriculum so that students apply those learned concepts with the focus of CT as well, it is not hard work to develop and implement STEAM programs into the classroom anymore. In this self- study, the researcher went through the journey of studying CT in order to move from being a novice to an expert. To perform this journey the researcher conducted an investigation of the established literature and developed a CT analyzing tool (CT_AT) drawing from a few sources. Continuing on the journey of CT discovery the researcher used the CT_AT to analyze 10 STEAM programs to explore how much CT practices can be found in the STEAM programs, which are not developed with the view of CT inclusion. The next step on the journey was to ascertain what kinds of CT practices can be suggested from the analyzed results to enhance missing or weakly exposed CT practices. It is hoped that teachers can use the developed CT analyzing tool (CT_AT) as a prescription for STEAM programs, or self-evaluation. By using the researcher's self-study journey as a template both pre-service and in-service teachers can increase their knowledge of each aspect of CT. In increasing their CT knowledge teachers will be able to modify existing module / lesson content and develop new content that exposes students to CT practices. The teachers can also use the CT_AT as a checklist to evaluate if students are exposed to CT practices. The researcher has also produced a CT guideline book (appendix) that teachers can use as a reference for good and confusing examples of each CT practice.

The research questions are as follows.

1. Based on learnt knowledge, what kinds of CT practices can be found in STEAM programs and what description of CT in STEAM can be illustrated?
2. Through continued professional development, what additional or extended CT practices can be suggested to revitalize STEAM programs on the basis of the descriptions made above?
3. After coming towards the end of self-study journey what difficulties are encountered when developing a new STEAM module from the viewpoint of exposing the students to CT practices?
4. From the experience gathered during the self-study how can the researcher develop a professional development program to aid pre-service and in-service teachers' in their own journey to study computational thinking?

The significance of this study can provide the practical strategies of how to analyze STEAM programs if there is CT practice and how to promote STEAM programs by adding concrete CT practices. This study will bridge the gap between theory and practice about CT practice introduced in science curriculum (MOE, 2015; NRC, 2012).

Chapter 2: Literature Review

The computational thinking of computer and technology education must be differently defined from that of science education. In this section, the newly constructed definition of computational thinking in science education will be explored on the basis of the original one in technology education in the papers.

2.1 The characteristics of computational thinking in science education

On the basis of our theoretical review about computational thinking (CT) in experimental papers, some characteristics of CT in science education can be withdrawn as follows. New definitions about CT in science education can be developed.

2.1.1 CT is an explicit skill in two steps of abstracting the problems and automating the solutions

The defining characteristic of CT is that it vacillates the exploration of problems and their possible solutions. This is why, with society's need to train creative problem solvers, CT can play an important part in STEAM/STEM education. CT is a problem solving skill that get progressively more sophisticated as the students get older (ISTE & CSTA, 2011).

In the seminal article (Wing, 2006; 2008) broke down CT into the 'The two A's of Computational Thinking', abstractions and automation. Abstractions are the mental tools that we use and they are the cognitive and intellectual skills that can be utilized to comprehend problems and then deduce and invent methods of solving the problems. The second A, automation is about the metal tools and they are the physical equipment, like any computer software, which is used to help solve problems. Some examples of metal tools are computers, calculators, thermometers, and graphing software to help visualize the results. Automation is mechanizing our abstractions, abstraction layers, and their relationships (Wing, 2008). The tools enable humans to handle the complexity and permit some of the tasks to be automated. It should be stressed that this is not the same as artificial intelligence, which is an attempt to copy human mental processes, but an amplification of human intelligence. So how can scientific literacy be interpreted with CT? CT can be included into the thought of as an extension of scientific literacy. The extension comes in how the solver tries to find the solution to the problem. According to Wing (2010), computational thinking describes the mental activity in formulating a problem to admit a computational solution, describing a two-step process of formulating the problem and then moving forward to find a solution computationally. Wing (2010) used the words ‘problem’ and ‘solution’ with a broad and wide-ranging definition.

The definition of CT offered by the Royal Society (2012) is “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).

Aho (2012) also discussed the two-step process idea of CT being about framing problems so that computational steps and algorithms can produce solutions. Nardelli (2019) however objects to the words ‘problem’ and ‘solutions’. He suggests the following formulation, “Computational thinking is the thought process involved in modeling a situation and specifying the ways an information-processing agent can effectively operate within it to reach an externally specified (set of) goal(s)” (para. 23). The change of ‘problem’ to ‘situation’ removes the implication of a required solution. The other difference is the emphasis that the goal(s) must be set externally so that the agent does not delineate the goal(s) itself. This more universally applicable definition of CT is useful from an educational viewpoint as it covers students’ use of simulations. Rutten et al. (2012) literature review of the learning effects of computer simulations in science education showed that simulations have a positive effect on students' motivation, attitude, efficiency of learning, and comprehension.

These two steps are also illustrated in Hwang (2019), where two experienced elementary teachers came to learn what CT is and how they employ it into their science teaching. Those two participating teachers developed their competencies of revising their curriculum for the purpose of using CT in their science lesson. For example, Mr. Son revised the curriculum of the 'seasonal change' unit, where he extended the latter part of the unit from 2 lessons to 5. Students at grade 5 designed a Korean folk village with different angles of its roof to get the least sunlight to avoid high temperatures in the room during summer. During this process, students calculated which angle of the roof is the best for summer and they tried to figure out how to measure the temperature with the use of Arduino so that they can close the window or curtain when the sunlight is too strong. Students used the program language UNO connected to Arduino for this function. This was a hard task for all of the students at elementary level to complete but at least they had chances to discuss which factors are the critical ones to be considered and how those factors are related each other in finding the solution. Students became to know how to face the problem, how to extract the factors making those problems, and to find the best solution. Students used digital thermometers in the rooms of the folk village and they made Arduino connected to the UNO program to send the signal to close the window or curtain to block the sunlight in summer. Students calculated the angle according to the solar altitude at meridian passage in Korea. At least students discussed what steps they need to consider in making decision to block the Sun's light in summer, which can be 'automation'. Here, Mr. Son provided two steps of CT, one is abstraction where students figure out what the problem is and where they learn concepts related to solve the problem; the other is automation where students could develop the algorithm to be automated with some points (like set up the digital thermometer connected to UNO and Arduino, calculate the angle of the roof according to the Sun's altitude etc. Mr.

Son indicated that he could form new understandings about CT and developed CT practices by revising the curriculum. In this paper, Mr. Son offered the chances for students to apply science concepts.

Nardelli (2019) stated that CT is not a new subject to teach and what should be taught in school is informatics, but he made a point it is very garbled when CT comes to education. A survey of educators about the meaning of CT would yield as many different answers as there were participants (Morris, 2004; Denning et al, 2006). So how can we teach CT in the classroom? How can we be sure CT is really effective in education? How can teachers learn to teach it? Nardelli (2019) described CT with two words 'problem' and 'solutions' illustrating CT as follows; Computational thinking is the thought process involved in modeling a situation and specifying the ways an information-processing agent can effectively operate within it to reach an externally specified (set of) goal(s). The change of 'problem' to 'situation' removes the implication of a required solution. The other difference is the emphasis that the goal(s) must be set externally so that the agent does not delineate the goal(s) itself. At least, CT can be defined into two steps where students can recognize and understand the given situation/problem and specify the ways to operate the information-processing agent operate effectively to reach the goals.

Repenning et al. (2017) breaks down CT into three stages. Those three stages are problem formulation, solution expression, and execution and evaluation. The first stage, problem formulation, which Repenning et al. (2017) likened to abstraction is conceptualizing problems. This could be done verbally or visually. The CT tools could drawings or writing out ideas. The second stage is solution expression, or automation. This is the framing of the issue in an understandable way for the computer. For the CT tools it is the ability to construct artifacts. The third stage is execution and evaluation, or analyses. This is the calculated result. The CT tools are visualization of the result such that the user can assimilate the result. Stage 3, execution and evaluation is mainly performed by computers and stage 2, solution expression, mainly by humans. Stage 1, problem formulation is "Although….typically considered the responsibility of humans, computers can help support the conceptualization process" (Repenning et al., 2017, p.293).

While Wing's 2006 article called for CT to be a part of school education within a range of disciplines it left questions unanswered. How can CT be observed to be taking place? What pedagogical strategy should be implemented to encourage CT in students? To answer these questions there needs to be a clear lexicography. The next section will look at attempts to provide that clarity.

2.1.2 CT consists of concrete components/practices to be observable and measurable

The second edition teacher resources for computational thinking (ISTE & CSTA, 2011) breaks CT down into nine different skills for students to master. Those skills are data collection, data analysis, data representation, problem decomposition, abstraction, algorithms and procedures, automation, simulation, and parallelization. The teacher resources gives the definition of each as follows: data collection is the process of gathering appropriate information. Data analysis is making sense of data, finding patterns, and drawing conclusions. Data representation is depicting and organizing data in appropriate graphs, charts, words, or images. Problem decomposition is breaking down tasks into smaller, manageable parts. Abstraction is reducing complexity to define the main idea. Algorithms and procedures is the series of ordered steps taken to solve a problem or achieve some end. Automation is having computers or machines do repetitive or tedious tasks. Simulation is the representation or model of a process. Simulation also involves running experiments using models. Parallelization is to organize resources to simultaneously carry out tasks to reach a common goal.

Park (2018) also released that there are two steps where teachers can use the 9 components of CT separately. Teachers in the study used the first three CT components in students' forming concepts related to the topic they learn for understanding the problem on the basis of curriculum. The last 6 components of CT were used in students' applying concepts for producing solutions on the basis of curriculum revised. Teachers were found to extend the latter part of the unit where students have chances to design the overhang of the roof of a Korean house by considering the Sun's light incident angle in different seasons (Hwang, 2019). Park, and Park, (2018b) also released that 9 components (generalization instead of parallelization) of CT can be found in STEAM programs from the lower elementary level to the high school level with those components. The relative dominating components usage of CT were withdrawn according to different school levels of STEAM program and those usages were changing from the lower and the higher levels in kinds and their frequencies. This implied that we can decide if there is CT component or not in the class teaching or science lesson.

Weintrop et al. (2015) developed their taxonomy through five steps. Step one was a literature review. This step was for Weintrop et al (2015) to discern an expansive and far-reaching view of what CT means before they focused on science and mathematics. Their review started with two CT reports by the National Research Council (NRC, 2010; 2011) and continued by investigating the papers cited in the two reports. As CT is still in its infancy with regards to science and mathematics they also analyzed papers from computer science, engineering, and technology backgrounds. The aim of the review was to determine concepts considered to be fundamental to CT. They compiled a list of ten skills as fundamental to CT. The following is the ten skills as set out by Weintrop et al. (2017, p.133) with some explanation by the researcher of what the skill would entail. The first skill was "Ability to deal with open-ended problems', which would show that student was able to approach problems that did not have a set structure laid out by the teacher and involved the student working towards an undefined solution to the problem. The second skill was "Persistence in working through challenging problems", which if demonstrated by the student would show that they do not give up when the problems is difficult to solve and that they can push through when difficulties and issues arise. The third skill was “Confidence in dealing with complexity”, which would show that the student can make decisions about what the problem encompasses and be confident that they can solve the problem at the required complexity. The fourth skill was “Representing ideas in computationally meaningful ways”. A student demonstrating this skill would be able to put forward their ideas in a manner that a computational tool is able to take on the problem and produce a solution. The fifth skill was “Breaking down large problems into smaller problems”, which would show that the student can decompose large complicated problems into smaller more manageable parts. The sixth skill was “Creating abstractions for the aspects of problem at hand”. A student demonstrating this skill can make a decision about what are the important factors of the problem that must be considered and if there are any parts can could be safely ignored without compromising the result. The seventh skill was “Reframing problem into a recognizable problem”, which would be the student considering is the problem is similar enough to another problem that the solution for another problem can be used to also solve this issue. The eighth skill was “Assessing strengths / weaknesses of a representation of data / representational system’. A student showing this skill would be able to evaluate the data or a system for how well it answers the problem at hand and whether it has any limitations. The ninth skill was “Generate algorithmic solutions”, which would show that a student can make an algorithm showing the process of the solution to the problem. The tenth skill was “Recognizing and addressing ambiguity in algorithms”. A student demonstrating tis skill would be able to find any issues within their algorithm and propose a way to fix the issue.

Step two was an open-coding of thirty-four classroom activities. The classroom activities were from a National Science Foundation funded program called “Reach for the Stars[1]” that covered a range of disciplines, such as, physics, biology, chemistry, earth sciences, astronomy, networks, and

[1] https://gk12.ciera.northwestern.edu/

programming. They also includes four lessons of a mathematical modeling class developed by a collaborating teacher. The thirty-four activities were analyzed by two researchers. The researchers found 208 examples of what they called "facets". These facets were coded from the ten fundamental skills from step 1. These skills had to be amended and adjusted as the facets were not represented or not well represented by the ten skills. The researchers concluded their analysis and presented a taxonomy of 45 CT skills.

An example of this analysis process presented in the paper was from a physics based activity to show students motion forces using a virtual roller coaster. In the activity the students are using a roller coaster builder. The CT facet that the two researchers coded this activity as being was building a model of a roller coaster that would could run to produce data about the potential and kinetic energy of the roller coaster. This facet was amended by the researchers to "Gain insight / understanding from computer-based simulations / models" (Weintrop et al., 2017, p.133). For the final taxonomy this would be two of the practices; Using computational a model to understand a concept, and constructing computational models.

Step three was a revision process by the larger research group. Most of the revisions centred on consolidating comparable skills. This process was validated through correspondence with graduate students from the "Reach for the Stars" program and in-service teachers. From this process emerged 27 skills grouped into five categories: Data and Information (6 skills), Modeling and Simulation (5 skills), Computation (5 skills), Problem Solving (7 skills), and System Thinking (4 skills).

In step four the taxonomy was shown to 16 high school teachers of mathematics or science. "The feedback from the teachers on the taxonomy was generally positive, but concerns were raised…" (Weintrop et al., 2015, p. 8). One of the concerns of the teachers was the Computation category. It was considered to be more computer science based and not science or mathematics based. The taxonomy was also shown to CT experts and STEM curriculum designers. Their unease was with the Problem Solving category. They considered some of the skills to be too general and not unique to STEM. This step finalized a taxonomy of twenty-two skills in four categories.

Finally step five was interviews with STEM practitioners. The practitioners were from a range of disciplines, such as, biochemists, physicists, material engineers, astrophysicists, computer scientists, and biochemical engineers (Weintrop et al., 2015). They wanted to make sure that the taxonomy accurately represented genuine scientific settings.

Weintrop et al. (2015) findings lead them to a taxonomy of four major categories and a total of twenty-two subset practices. The following is the twenty-two skills with a definition from the researcher. Although the practices are presented in an order it should be noted that they are not a step-by-step process. The first major category to look at is the data practices. This category consists of five subset practices. First, there is ‘collecting data’, which is data collected through observation or measurement. The second practice is ‘creating data’. This practice is using computational tools to generate data when investigating phenomena that cannot be observed or measured easily. Next, there is ‘manipulating data’, which is reshaping the dataset to be in the desired or useful configuration. Includes the sorting, filtering, cleaning, normalizing, and joining of datasets. The next practice in this category is ‘analyzing data’. This practice involves looking for patterns, or anomalies, defining rules to categorize data, and identifying trends and correlations. The final practice in this category is ‘visualizing data’, which means producing graphs and charts to help communicate results.

The second major category is modeling and simulation practices. There are five subset practices in this category. First, there is ‘using computational models to understand a concept’, which involves the students using computational models to form concepts of a phenomena. Second, 'using computational models to find and test solutions'. This practice means using computational models help students to apply their understanding of the concepts of a phenomena to see if their concept is correct. Third, there is 'assessing computational models'. This practice is assessing how faithfully the model represents the phenomena. The next practice is 'designing computational models', which means making the technological, methodological, and conceptual decisions need to design a model. The final practice of this category is 'constructing computational models'. This practice could be the actual making of new models or the adjustment of an existing model.

The third major category is computational problem solving practices. There are seven subset practices in this category. The first practice is 'preparing problems for computational solutions'. This practice is the breaking the problem down into sub-problems and reframing them in such a way that a computational model can be used to find a solution. The next practice is 'programming', which is the writing of computer code either of a new program or modifying an existing program. Next, there is 'choosing effective computational tools' which means choosing a computational tool based on its range of use, adaptability, and whether the tool fits well with the planned data inputs and wanted outputs. The fourth practice is 'assessing different approaches / solutions to a problem'. This practice means that students evaluate different ways to solve the problem. For example, they could be considering aspects such as cost, time, durability, extendibility, reusability, and flexibility. The fifth practice in this category is 'developing modular computational solutions'. By having a modular solution to a problem it means that there is a greater chance that they can be used again to help solve future problems. The sixth practice is 'creating computational abstractions'. This practice is bring the most important aspects of a phenomena to the front while relegating the less important aspects to the background. The final practice of this category is 'troubleshooting and debugging'. This practice is finding, isolating, duplicating, and rectifying computational tools that are giving unpredicted results.

The fourth major category is system thinking practice. This category has five subset practices. First, there is 'investigating a complex system as a whole'. This practice is about the student considering the input and output of a system without worrying about how the different elements of the system are interacting with each other. The second practice is 'understanding the relationships within a system', which is the student considering the connections between the different elements of a system, and how changes in one elements can affect another element. The third practice is 'thinking in levels'. This practice means being able to look at individual elements of a system as well as the system as a whole. The fourth practice is 'communicating information about a system', which means being able to tell others about the system and the solution that has been produced. The fifth practice is 'defining systems and managing complexity'. This practice is setting what the system encompasses and how much complexity is to be involved to produce a useful solution.

One of differences between the two systems is that ISTE and CSTA define the components as skills while Weintrop et al. (2015) name the components as practices. This difference came about due to input from high school science and mathematics teachers as part of a workshop where they were asked their opinions on the taxonomy. The teachers suggested the change as practices are "... broader and more actionable" (Weintrop et al, 2015). This is in line with the general trends in both science and mathematics pedagogical thinking to highlight the need for knowledge not just skill (NGSS Lead States, 2013). The skills by the ISTE and CSTA can be observed and described individually. The CT practices suggested by Weintrop et al. (2015) consist of concrete behaviors; data practices, modeling & simulation practices, computational problems solving practices, and system thinking practices, which can be described integrally.

Park and Hwang (2017) illustrated what practices of CT can be taking place during the STEAM class (Table 1).

Table 1. The Protocols of Computational Thinking Practice (Park & Hwang, 2017)

CT practice		CT protocol
1	Connecting Computing, CC	CC-1) Use computing to facilitate exploration and the discovery of connections in information. CC-2) Use computers to process information to gain insight and knowledge. CC-3) Appropriately connect problems and potential algorithmic solutions.
2	Developing Computational Artifacts, DCA	DCA-1) Use computing tools and techniques to create artifacts(creative expression). DCA-2) Develop an algorithm designed to be implemented to run on a computer.
3	Abstracting, Abs	Abs-1) Develop an abstraction. Abs-2) Describe the combination of abstractions used to represent data. Abs-3) Use large data sets to explore and discover information and knowledge. Abs-4) Use multiple levels of abstraction in computation. Abs-5) Use abstraction to manage complexity in program.
4	Analyzing Problems and Artifacts, APA	APA-1) Analyze the considerations involved in the computational manipulation of information. APA-2) Evaluate algorithms analytically and empirically. APA-3) Evaluate a program for correctness. APA-4) Employ appropriate mathematical and logical concepts in programming. APA-5) Analyze how characteristics of the internet and the systems built on it influence their use. APA-6) Analyze how computing affects communication, interaction, and cognition. APA-7) Analyze the beneficial and harmful effects of computing.
5	Communicating & Collaborating, Co-Co	Co-Co-1) Communicate insight and knowledge gained from using computer programs to process in information. Co-Co-2) Express an algorithm in a language. Co-Co-3) Explain characteristics of the internet and the systems built on it. Co-Co-4) Connect computing with innovations in other fields. Co-Co-5) Connect computing within economic, social, and cultural contexts. Co-Co-6) Collaborate to solve a problem using programming.

If we apply the individual 9 components as suggested by Park, and Park, (2018b) to see if there is CT or not, we can show the results of CT usage of which one and how much. However, we do not know how those components are interacting with each other in the context of forming and applying science concepts. Park and Hwang (2017) extracted five different practices with 23 protocols illustrating each practice, where we can recognize how those practices are interacting each other (Fig. 1). In the figure the codes are as follows CC is connecting computing, DCA is developing computational artifacts, Abs is abstracting, APA is analyzing problems and artifacts, and Co-Co is communicating and collaborating.

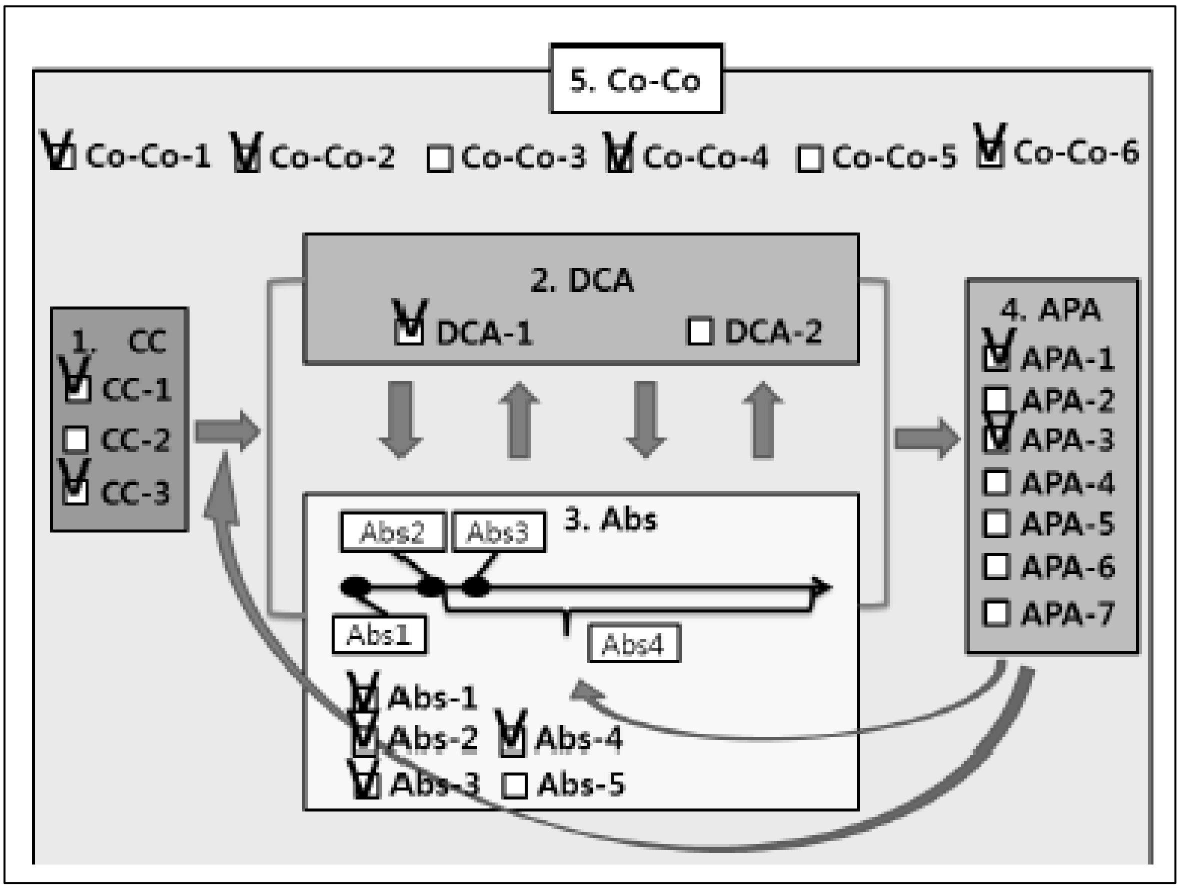


Figure 1. CT practice checklist/flow in the context of STEAM (Park and Hwang, 2017).

In figure 1, Park and Hwang (2017) describes what kinds of CT practices students showed while performing their STEAM activities about climate change (middle school level) to find out the best solution. The authors described how science learning and teaching occur and how students formed and applied concepts which they learnt during science lessons guided by a teacher. Students recognized the problem of climate change in the city where they live. Therefore, students had to decide what data were appropriate to indicate that the city also experienced climate change, how to collect the data, and how to transform these data to be represented. Students learnt concepts about climate change through experimentation and argumentations offered in the program and they also discussed and decided which way is the best solution to reduce CO2 in the city where they live and where there are many chemical factories. Students designed the photo bioreactor to see how efficient this solution is. During these all processes, students had chances to experience all CT practices (Table 1), mainly CC, Abs, and CoCo. The authors described that CC and Abs and CoCo practices are more dominating than other two practices; APA and DCA.

The CT practices described in the STEAM program of climate change showed what and how CT practices are interacting each other (Fig. 1). CC practice had been initialized at the beginning of the program, and DCA and Abs interacted each other to be connected to APA. Co-Co practice covered all context of practices during the 10 lessons of climate change STEAM program. On the basis of those findings, the researcher in this study is trying to find out the relationship between the 9 components of (Park, and Park, 2018b) and the CT practices (Park and Hwang, 2017), which can be developed as a guideline with practices and components. If the researcher could make this guideline, it will be much easier for teachers to employ CT in the science classroom. This guideline can be used as planning and assessing tool for measuring CT skills.

2.1.3 CT is a catalyst for STEAM education

Over the past twenty to thirty years students' use of technology in the classroom (and people's everyday use) has increased drastically. Indeed, the term 'digital natives' is a growingly used term to describe the younger generations. It is as if young people grow up instinctively knowing how to use technology, to use social media to connect with friends, watch the latest music videos on the internet, and play online games. Does this knowledge really make them fluent in the use of technology, however? Could those same young people program a simulation of a container of gas molecules, or even create their own game? Coyle (2012) succinctly phrased it, "It's as if they can read but not write".

So, the question is why can these young people not 'write' when it comes to the use of technology? Margolis et al (2008) argues that these 'writing' skills are seen as (especially by females and people of color) as something for only the "best and the brightest". Henderson et al (2007) uses the analogy, "People can look at the night sky to better understand what an astronomer does, whereas using a computer, cell phone, PDA, etc. provides little insight into what a computing professional does." It is seen as something that they cannot do. It is not uncommon to hear people to claim that they don't have a science brain or that they are no good with numbers. The poor image that having a career in computing has with students is often cited as one of the reasons why talented students do not pursue computing industry careers (Henderson et al, 2007). The issue of poor female presentation in science subjects was reported by the Royal Society (2012). The report gives the percentage of male and female representation in computing, ICT, Mathematics, Physics, and Biology in the years 2002 through to 2011. For every year and every subject male representation is higher than female, with in 2011 the higher level of female representation being 47% in Chemistry, and the lowest being 8% for Computing. The subjects of Computing, Physics, and Chemistry saw a decrease in female representation from 2002 to 2011, but ICT and Mathematics saw an increase. For all the subject, however, the numbers have stayed roughly the same showing attempts to raise the level of female representation have not worked. The term ICT stands for Information and Communications Technology, which is the component of the UK national curriculum under which computing was taught. Computing is now a part of The Computing Curriculum (Computing Curriculum, 2019).

As discussed earlier about the purpose of science education in the 4th industrial revolution, STEAM subjects need to equip students with competencies to be literate scientifically through scientific inquiry. That has always been the case, but it is especially true now with the extensive use of computers in STEAM fields. The idea of the scientist of the future who does not know to use a computer to manage data and run simulations will seem as strange as a scientist who does not know algebra (Foster, 2006).

STEAM subjects need a way to solve both of these issues. The need to properly train and prepare students for their future in STEAM and to help keep the interest of students and encourage students from all backgrounds to actively participate in classes. The answer to both of these needs is bringing CT into the STEAM classroom. CT can provide the training that students will need in their future careers. CT can introduce computing to students by using computing in conjunction with situations they are already familiar with (Henderson et al, 2007). It also makes sure that everyone is exposed to CT practices. When these practices are only taught in elective or afterschool classes then there is an underrepresentation of females and minorities in those classes (Margolis and Fisher, 2003). They found that the computer science department of the Norwegian Institute of Technology had the lowest percentage of students, at only 8 percent, of all the different departments. They also found that in 1999 only 7 percent of Advanced Placement (AP) students in computer science classes were African American or Hispanic.

Park, and Park, (2018a) released the possibility of including CT in STEAM program. The purpose of STEAM education is to equip students with competencies to be creative problem solvers and those programs have been developed to meet this goal. Therefore, students had chances to explore what problems they could face in their community and what solution would be best based on their evaluations. In this study, the implication of STEAM education had been withdrawn as follows; CT can promote students' opportunities of using technology as well as engineering disciplines for envisioned STEAM education. This study released the differentiated CT practices had been observed at different levels during a STEAM program, where simple CT practices had been observed at elementary levels and more advanced ones at high school level during climate change and water shortage STEAM lessons. Park, and Park, (2018b) stated the result of this study can support the CT framework defined by NGSS (2013). On the basis of this study, the authors also emphasized the critical role of teacher education for computational thinking.

Weintrop et al. (2015) also illustrated the reciprocal relationship between CT and, science and mathematics. For example, of DNA sequencing from the ground up, students had chances to reassemble the songs related to the problem, which has been assessed by different approaches. Students also went on to more difficult challenges: reconstructing an unknown password with an unfamiliar combination of letters and numbers. Then they applied their technique to derive an efficient, robust, and general algorithm for sequencing this, which are the steps of preparing problems for computational solutions, creating computational abstracts. CT practice in this student work promotes students learning science. There is another example where high school students use an interactive simulation to explore the relationship between the macroscopic properties of gases based on how those properties emerge from microscopic interactions, which could make students build conceptual understandings. Students were observed to use practices of computational models to understand a concept. These are all cases of examples where students used CT practices named by the authors in this study.

2.1.4 CT is a cognitive process to be learned

"Computational Thinking will be a fundamental skill used by everyone in the world by the middle of the twenty-first century" (Wing, 2008). This means that CT is not just a skill to be used by experts in their fields or by students just looking to get a good grade on their test. It is used by everybody every day.

As computational thinking is such a crucial skill for everybody, it is important that students are taught about computational thinking and how to do it successfully. To reading, writing, and arithmetic, we should add computational thinking to every child's analytical ability (Wing, 2006). Some examples of how the average person might think computationally in their everyday life might be deciding how to get to work that day, take the bus, a taxi, or drive the car. Trying to find out why the light isn't coming on, scanning the barcode of the groceries at the self-checkout line. Deciding the mode of transport to get to work is an example of performing an algorithm. The person needs to make decisions based on the time it would take to get there (are they late and need to be quick), how much would it cost (they only have a little change in their pocket), what time of day is it (rush hour or quiet roads)? The person would need to go through these questions and ask themselves what is the best mode of transport for them. Finding out why the light isn't working is problem decomposition. The person would break the problem down into the possible reason that the light is out. Has the bulb blown, a problem with the light switch, faulty wiring, has the fuse blown or is the power for the whole block out? When going through the self-checkout line and scanning the products the person is performing automation. The till will automatically scan and read the barcode, keep a tally of the cost, and accept payment.

The skills and practices of CT may also be of use in peoples' workplaces. For example, managers could evaluate the workings of the office to try and increase efficiency. Warehouse managers can track inventory to help with the shipping of orders and the need to purchase more stock. Government policy makers can also use CT to help inform policies. They could study large amounts of data on traffic to see if a change to the traffic light system could reduce the amount of car accidents. CT could be used to analyze voting data to determine the true will of the people.

Students at schools also need to be trained for this cognitive skill. Teachers need to provide certain questions for students' experience of CT skills. Without training in using CT skills, students cannot know how to face the problem, what data to collect, and what solution to produce. CT is a structured and proven method designed to identify problems regardless of age and computer literacy level. Students must learn how to decompose the given problem to be researchable. For example, teachers can ask, what is the problem? What factors can you find in the problem? What patterns can you find? CT users must be innovators. Teachers ask students to use different perspectives to determine what to extract from a problem in order to create a solution by continuous evaluations. What kinds of pros and cons can you find in this process or solution? How can you make this better economically? Why is this appropriate or not? By doing this training, students can leap from consumers to creators to meet the goal of science education, scientific literacy (Cummins, 2016; Hwang, 2019; Nardelli, 2019; Park, 2018). There are many reports and discussions regarding CT practices stating as follows; there is not common definition of CT now among scholars but we all agree that CT is a pivotal skill for people to live in the 21st century, where people understand a problem and formulate a solution. For this, the CT cognitive skills must be experienced from elementary level to equip students with competencies to be creative problem solvers (Park, and Park, 2018a).

2.2 The differences between the CT of science education and computer science

Much of the discussion regarding the comparing how CT is different between the viewpoints of science education and computer science tries to find analogies between the two (Weintrop et al., 2015). Some examples of these analogies are the CT skills involving data, such as, collection, analysis, and representation/visualization. These skills will be familiar to everyone in science education. Weintrop et al. (2015) took a different approach by developing a taxonomy with definitions of how CT applies in a science and mathematics context.

Park, and Park, (2018b) conducted a study to look at the instances of CT practices in two STEAM programs, a climate change STEAM program and a water shortages STEAM program. They used a computer science definition of CT from CSTA (2011) which has 9 components. The 9 components are as follows; *data collection, data analysis, data representation, problem decomposition, abstraction, algorithms & procedure, automation, simulation, and parallelization*. They reason for using these components was to see if they are pertinent from a science education viewpoint. The research team of science educators and teachers looked at the STEAM programs at 4 levels, lower elementary, upper elementary, middle school, and high school. The results are shown in the following tables 2, 3, 4, and 5. Table 2 presents the lower elementary results.

Table 2. Profile of CT components in STEAM programs ('climate change' & 'water shortage') for lower elementary level (Park, & Park, 2018b).

	Climate change					Water shortages					
	1	2	3/4	5	6	1	2	3	4	5	6
Data Collection		○	○	○				○		○	
Data Analysis	○	○	○	○		○	○	○		○	
Data Representation	○	○	○	○	○	○		○	○	○	○
Problem Decomposition		○	○			○			○		○
Abstraction		○	○								
Algorithms & Procedures							○				
Automation											
Simulation									○		
Parallelization											

Table 3 presents the results for the upper elementary level.

Table 3. Profile of CT components in STEAM programs ('climate change' & 'water shortage') for upper elementary level (Park, & Park, 2018b).

	Climate change						Water shortages					
	1	2	3	4	5	6	1	2	3	4	5	6
Data Collection	○	○	○	○	○	○	○	○	○	○	○	○
Data Analysis	○	○	○	○		○	○	○	○		○	
Data Representation	○					○	○	○			○	○
Problem Decomposition						○				○	○	○
Abstraction						○				○	○	○
Algorithms & Procedures												○
Automation												
Simulation										○		
Parallelization												

Table 4 presents the result for the middle school level.

Table 4. Profile of CT components in STEAM programs ('climate change' & 'water shortage') for middle school level (Park, & Park, 2018b).

	Climate change									Water shortages									
	1	2	3	4	5	6/7	8	9	10	1	2	3	4	5	6	7	8	9	10
Data Collection	○		○	○	○					○		○				○			
Data Analysis		○	○	○	○					○	○	○				○			
Data Representation		○							○	○		○				○			○
Problem Decomposition	○	○			○	○				○	○	○	○		○		○		
Abstraction	○	○			○	○				○	○	○	○		○		○		
Algorithms & Procedures					○	○							○	○	○			○	
Automation						○	○						○	○					
Simulation							○							○				○	
Parallelization																			

Table 5 presents the result for the high school level.

Table 5. Profile of CT components in STEAM programs ('climate change' & 'water shortage') for high school level (Park, & Park, 2018b).

	Climate change									Water shortages									
	1	2	3	4-5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Data Collection	○	○	○	○		○	○		○	○	○	○	○	○	○	○	○		○
Data Analysis	○	○	○	○		○	○		○	○	○	○	○	○	○	○	○		○
Data Representation	○	○	○	○		○	○		○				○	○	○	○	○		
Problem Decomposition	○	○	○	○		○	○		○			○	○	○	○	○	○		
Abstraction	○	○	○	○		○	○		○			○	○	○	○	○	○		
Algorithms & Procedures		○		○					○				○	○	○	○	○		
Automation		○		○				○	○				○	○	○	○	○		
Simulation				○	○			○	○					○		○		○	
Parallelization																			

As can be seen from the results as the level went higher the range of CT practices that were covered increased. The lower and upper elementary levels were dominated by the three data related practices, while the high school level recorded instances of all the CT practices with the exception of parallelization.

Parallelization can be seen to be important in computer science as there needs to be management of computing resources. This management of resources is of less importance for science education. Doing multiple experiments at the same time is data collection done multiple times (Park, & Park, 2018b). Park, and Park, (2018b) conclusion was that parallelization should be replaced with generalization. They provide this definition of generalization, “apply the product in various types of context if it is working or not” (Park, and Park, 2018b, p. 396). This change of parallelization to generalization is a difference of science education CT and computer science CT.

2.3 The need for measuring student progress

There is debate amongst educators about the distinction between the terms mastery, competence and proficiency (Guskey & Anderman, 2013). Whatever the name that is used teachers are looking for how to evaluate the students’ mastery, competency, or proficiency of the subject, especially with CT being explicitly mentioned in curriculums. However, despite the need of teachers for a way to measure their students, only a few ways exist to measure CT (Brasiel et al, 2017). These few methods of assessment will be more applicable to computer science rather than science education. This is because the methods make their assessment of the students’ CT skills by judging their programming abilities. Some examples of these methods can be found in Fields et al. (2012), Koh et al. (2014), Meerbaum-Salent et al. (2013), Werner et al. (2012), and Werner at al. (2015). Programming is a CT practice given in the researcher’s CT_AT tool, so assessing programming could be useful for the science education classroom. An automatic method of checking the students’ work is needed as going through the code one-by-one would take a long time, and would an idiosyncratic judgment (Grover, 2017).

One such method of measuring students’ CT ability has been developed by Moreno-Leỏn & Robles (2015). They developed a Hairball plug-in called Mastery. Hairball was developed by Boe et al.

(2013) as a way to appraise Scratch projects. Mastery analyzes students' Scratch programmes on seven concepts: abstraction and problem decomposition, parallelism, logical thinking, synchronization, algorithmic notions of flow control, user interactivity, and data representation (Moreno-León & Robles, 2015). Table 6. Shows how they evaluate the level of development shown by students for the seven concepts. Based on how the students score on each concept they would give them an overall CT score. A score of 0 to 7 points were *Basic* CT, students scoring between 8 and 14 points received a *Developing* grade, and finally any students scoring over 15 point were considered *Proficient*.

Table 6. Level of development for each CT concept (reproduced from Moreno-Leòn & Robles, 2015)

CT Concept	Level	Moreno-Leòn & Robles Description	Researcher's Description
Abstraction and problem decomposition	Basic	More than one script and more than one sprite.	A script is a set of commands that are interlocked with each other. A sprite is an image that the students can use.
	Developing	Definition of blocks	Blocks are the shapes that are used to make a code in scratch.
	Proficiency	Use of clones	Cloning means that a copy of a sprite can be made that mimics the original's code.
Parallelism	Basic	Two scripts on green flag	Two script run at the same time with only one click.
	Developing	Two scripts on key pressed, two scripts on sprite clicked on the same sprite	Two scripts are run when the sprite is clicked.
	Proficiency	Two scripts on when I receive message, create clone, two scripts when %s is >%s, two scripts on when backdrop change to	'I receive messages' are codes that run when a broadcast is received.
Logical thinking	Basic	If	Runs the code if the condition is true.
	Developing	If else	If the condition is true then the code will run the block. If the condition is false then another block of code will run.

	Proficiency	Logic operations	Code that checks to see if two conditions are true or false.
Synchronization	Basic	Wait	Code that triggers a pause for a set length of time.
	Developing	Broadcast, when I receive message, stop all, stop program, stop programs sprite	Code that causes either everything or certain code to stop running.
	Proficiency	Wait until, when backdrop change to, broadcast and wait	'Wait until' is code that causes the code to pause until a condition is true.
Flow control	Basic	Sequence of blocks	Steps of code in a sequence.
	Developing	Repeat, forever	A loop of code that will repeat forever.
	Proficiency	Repeat until	A loop of code that will repeat until a condition is true.
Use Interactivity	Basic	Green flag	A green flag is the symbol that can be clicked to start running a code.
	Developing	Key pressed, sprite clicked, ask and wait, mouse blocks	Code that asks a question of the user and waits for an answer.
	Proficiency	When %s is >%s, video, audio	Senses for motion or sound and reports the information.
Data representation	Basic	Modifiers of sprites properties	Change a property of a sprite.
	Developing	Operations on variables	Perform an operation on the value of a variable.
	Proficiency	Operations on lists	Perform an operation on a list of variables.

Below in are examples made by the researcher[2] that would be graded as basic (figure 2), developing (figure 3), and proficient (figure 4) under their CT concept of 'Logical Thinking'. The basic level code (figure 2) show the student using only *if* statements, which will affect the size of the sprite based on the value of variable 'x'. If 'x' is greater than 5 then the size of the sprite will be set to 100%. If the value of 'x' is less than then the size will be 70%.

[2] Figures 2, 3, and 4 are captured and shared under the 'Creative Commons Attribution-ShareAlike 2.0 license' from https://scratch.mit.edu/

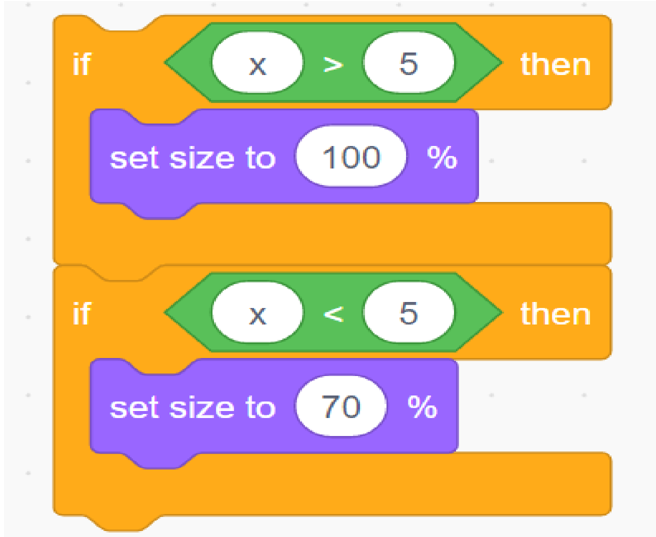


Figure 2. An example of basic level code (captured and shared under the 'Creative Commons Attribution-ShareAlike 2.0 license' from https://scratch.mit.edu/)

Figure 3 below shows code that would be considered as the developing level as it uses an *if else*. This code checks if a condition has been met. If the condition is true then it performs one action and if it is false then another action is performed. In the example the condition is if x is greater than 5. If this is true then the size is set to 100%, else the size is set to 70%.

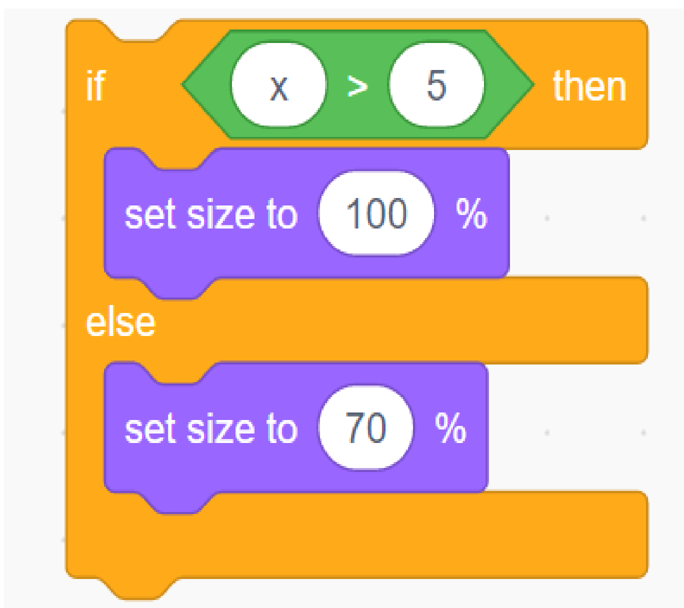


Figure 3. An example of developing level code (captured and shared under the 'Creative Commons Attribution-ShareAlike 2.0 license' from https://scratch.mit.edu/)

Figure 4 below shows an example of code that would be graded as proficient. It is considered to be proficient as the student has used an *or* operator. In this example the condition the code is checking if 'x' is greater than 5 or 'x' is equal to 5. There is then code to run if the condition is true or if it is false.

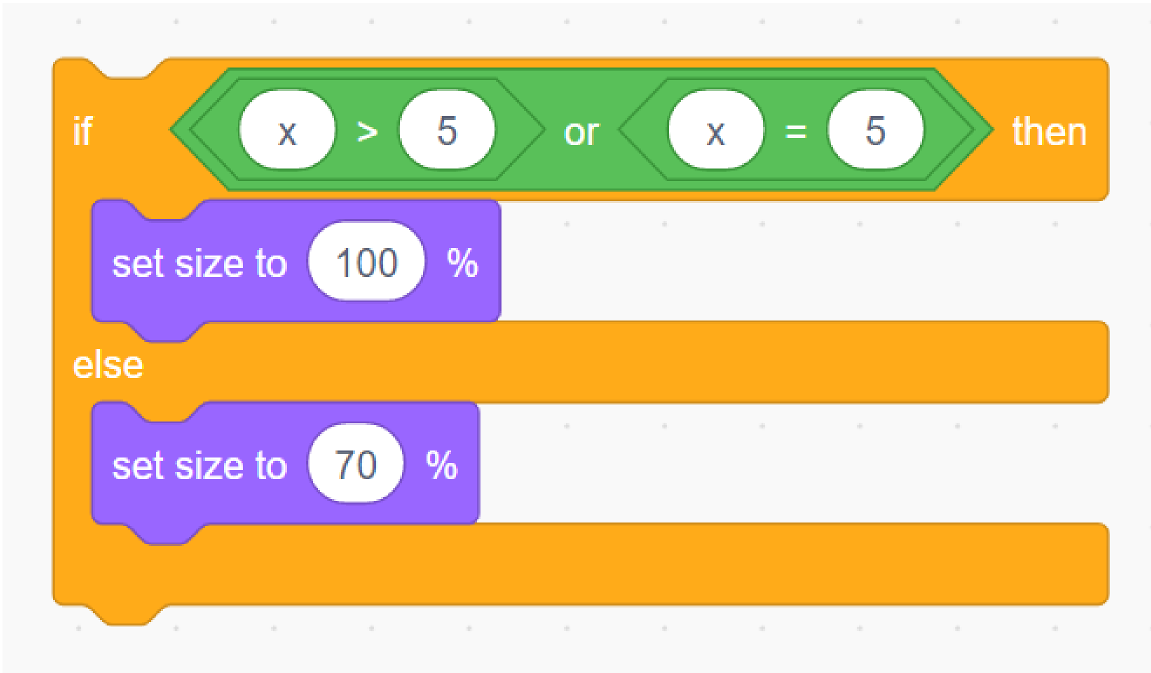


Figure 4. An example of developing level code (captured and shared under the 'Creative Commons Attribution-ShareAlike 2.0 license' from https://scratch.mit.edu/)

In order to test their *Mastery* plug-in, Moreno-Leȯn & Robles (2015), used the Scratch repository to analyze 100 randomly downloaded projects. They report that the average total score was 14.4 points, with a median of 16 points and a mode of 18. The average of 14.4 points is just below the cut off of 15 points which would signify a proficient level. In their report Moreno-Leȯn & Robles (2015) report some limitations of this method of assessing students' CT ability. The researcher agrees with their conclusions of the limitations. Their conclusions were that the tool was limited as it does not measure some aspects of CT, such as debugging or remixing. Their appraisal is that this method could be used to offer observations on the students' projects to guide them in areas in need of improvement or further study.

Work needs to be done to design and develop tools that teachers can use to analyze their students competency in CT (Brennan & Resnick, 2012). Research also needs to be done to see if the existing tools developed for the computer science classroom would also be useful in the science classroom. This is outside the scope of this study but it warrants study in the future.

2.4 The need for CT training for teachers

The enthusiasm for CT as a part of the curriculum has been going up in many countries all around the world (Liu et al., 2011). The majority of effort for training teachers in CT is aimed towards pre-service teachers (Yadav et al. 2011, 2014). However, with education guidelines calling for teachers to introduce CT into their classrooms, in-service teachers also need guidance about CT. The task of incorporating CT into curriculums around the world is extensive and there will be many challenges to be faced by teachers (Bower et al., 2017). Whenever a new curriculum and/or concepts are introduced there is worry about the number of teachers qualified to be able convey them to students (Peng et al., 2014). Teachers are concerned when they are required to establish new teaching resources (Meerbaum-Salant et al., 2013).

The constructs that pre-service teachers (and teachers undergoing professional development programs) develop early in their training career need to be considered (Jones & Carter, 2007). These constructs can guide their classroom practices (Luft et al, 2011). A study of pre-service kindergarten teachers, who received training in the ScratchJr educational program showed a statistically significant increase in the teachers' understanding of CT and also their willingness to make use of CT in their science education classrooms (McLoughlin et al, 2019). This study shows that to be effective, teachers need to have an understanding of the material and/or skills that they are teaching their students.

Sands et al. (2018) conducted a study of 74 teachers in Midwestern America to investigate the teachers' knowledge of CT concepts. The covered a range of age group with 45 of the teachers being primary school level and 29 being secondary school level. They teachers also taught a range of subjects with 29 of the teachers mainly teaching STEM subjects and 45 non-STEM subjects. 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 / algorithms, 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 researchers studied the literature and recorded their opinion of what CT involves. They opinion is that four of the above ten phrases are what CT involves. Those four are solving problems, using heuristics / algorithms, logical thinking, and thinking like a computer. There were five phrases that the researchers considered CT not to involve. Those five phrases are doing mathematics, using computers (e.g. office tools), knowing how to use a computer, using technology in your teaching, and playing online games. They considered unclear if CT involves the phrase coding / programming.

The teachers were asked if they 'strongly agree', 'agree', 'disagree', 'strongly disagree', or 'don't know'. 100% of the teachers said that CT involves logical thinking and doing mathematics. That agrees with the researchers' opinion with regards with logical thinking, but disagrees on the matter of doing mathematics. While the majority of teachers strongly agree or agree that playing online games, thinking like a computer, and knowing how to use a computer, there are the three phrases that most teachers disagreed or strongly disagreed with CT involving. 27% of teachers disagreed / strongly disagreed that CT involves playing online games. 25% and 24% of teachers disagreed / strongly disagreed that CT involves thinking like a computer and knowing how to use a computer respectively. This agrees with the opinion of the researchers with regards to playing online games, and knowing how to use a computer, but disagrees with the opinion of the researcher with regards to thinking like a computer.

Sands et al. (2018) study showed that teachers do have some overlap with the established literature in their understanding of CT, they also have some “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). A study of science teachers in Lebanon by BouJaoude & Saad (2012), while looking for attitudes towards science inquiry rather than computational thinking, showed that only one of the 34 teachers observed had 50% of their response deemed acceptable and 65% of the teachers did not practice enough inquiry in their teaching.

A study by Bower et al. (2017) set-out to determine whether a workshop could promote teachers’ CT knowledge, and their pedagogies. The workshop covered four modules; problem decomposition, patterns, abstraction, and algorithms (Bower et al., 2017). The modules included explanations of important concepts, activities to expose the teachers to the CT concepts, and discussions. A survey of the teachers was done pre-workshop and post-workshop in order to evaluate the change in the teachers’ knowledge and pedagogies. The survey used a seven point Likert scale with answers from ‘strongly agree’ to strongly disagree’ (Bower et al., 2017), with 69 teachers completing both pre- and post-workshop surveys.

The teachers were asked about what they consider to be the constructs of CT. When asked “*What does computational thinking mean to you?*” (Bower et al., 2017, p. 59) pre-workshop the teachers’ answers came under five categories with the numbers of answer given in parentheses; computational practices (101), misconceptions (24), computational concepts (7), computational perspectives (6), and others (3). The three most common answers under the computational practices category were problem-solving with 32 instances, logical thinking with 16 instances, and writing scripts or coding answered 12 times. The most common answer for the misconceptions category was using technologies (generally) mentioned 13 times. Sequences at 4 instances was the most common answer in the computational concepts category. For computational perspectives, 21st Century skills was the most common answer with 4 answers. Unsure at 2 mentions was the most common answer for the others category.

When the teachers were asked about CT constructs post-workshop there were answers under four categories; computational practices (279), computational concepts (17), computational perspectives (13), and others (3). Therefore the total number of answers changed from 141 for the pre-workshop survey to 312 for the post-workshop survey. The top three answers under the computation practices category was problem decomposition with 62 instances, problem-solving with 60 instances, and pattern recognition with 46 instances. The first difference to be noticed is the increase of instances. Pre-workshop the category of computational practices had 101 instances, while post-workshop that number had increased to 279. Of the three top answers, problem-solving remained in the top 3, but logical thinking and writing scripts or coding have been replaced by problem decomposition and pattern recognition.

Sequencing remained as the top answer for the computational concepts but the number of instances increased from 4 to 14 post-workshop. For the category of computational perspectives the top answer has changed from 21st Century skills to tackling real-world issues. In the pre-workshop survey 21st Century skills has 4 instance while in the post-workshop survey there were 7 instances. Under the category of others the pre-workshops answers were unsure and haven't heard of computational thinking before. Post-workshop the only answer under the others category is no computer is needed.

The study also aimed to determine if the workshop could promote pedagogical strategies for teaching CT. To answer this question the teachers were asked the open-ended question "*What* *pedagogical strategies do you have (or can you think of) for developing school students' computational capabilities?*" (Bower et al., 2017, p. 61).

The pre-workshop survey asking about pedagogical strategies were under three categories. The categories and the number of instances were student-centred pedagogy (59), teacher-centred pedagogy (30), and others (10). The three most common answers for the student-centred pedagogy category were problem-solving approach with 25 instances, student-oriented learning approach with 15 instances, and open-ended tasks with 8 instances. The top two answers for teacher-centred pedagogy were basic usage of technologies and software application with 12 instances and programming or coding related activities with instructions with 10 instances. The number one answer under the others category was not sure with 9 instances.

For the post-workshop survey the answers are again found under three categories; computational practices (132), teacher-centred pedagogy (29), and others (31). Therefore the total number of answers changed from 99 for the pre-workshop survey to 192 for the post-workshop survey. The top three answers for the computational practices category were problem-solving learning using the four cornerstones of CT with 88 instances, student-oriented learning with 18 instances, and open-ended tasks with 6 instances. These appear to be the same three answers as were found for the student-centred pedagogy category in the pre-workshop survey. There are, however, differences. The post-workshop survey problem-solving includes using the four cornerstones of computational thinking. There is also a difference with the student-oriented answers. For the pre-workshop there were some examples given of peer-to-peer learning, support students' learning, and skills development. However, in the post-workshop survey the answer had examples of develop students' thinking abilities, self-reflection tasks, and skills development.

The most common answer of the teacher-centred pedagogy category remains the same pre and post-workshop survey with basic usage of technologies and software applications, but the number of instances increases from 12 to 16. Programming or coding related activities with instructions, however, decreases from 10 to 5 instances. The most common answer for the others category in the post-workshop survey is embedded in all key learning areas and curriculum, which has 16 instances. The number of instances for the answer of not sure has decreased from 9 in the pre-workshop survey to 3 in the post-workshop survey.

It is also important that teachers demonstrate confidence when teaching. Students receiving instruction from teachers who do not have confidence in the subject they are teaching, will have an unfavourable opinion of the subject (Duncan et al, 2014; Bean et al, 2015). A study by O'Sullivan (2002) of unqualified and underqualified teacher in post-apartheid Namibia showed that professional develop through group and pair discussions, guided learning, and reflective questions increased the teachers' participation and confidence in the subject matter. This learning, learning how people learn, and also how to convey this learnt knowledge into their classrooms to aid in the students' improvement is at the core of professional development for teachers (Avalos, 2011).

Bower et al. (2017) also addressed the issue of teacher confidence. They asked teachers the question, "What prevents you from feeling confident about developing your students' computational thinking capabilities?" (Bower et al., 2017, p. 62). The teachers were asked this question both before and after a workshop. The pre-workshop survey reported answers under three categories; low self-efficacy (78), lack of resources (19), and others (3). The top three answers for the low self-efficacy category were lack of knowledge and ability to understand computational thinking with 36 instances. Next there was lack of effective teaching strategies with 14 instances, and lack of experience, practice and training with 13 instances. The three most common answers for the lack of resources category were not aware of the support, funding, activities, programs that are available with 9 instances, lack of time with 7 instances, and lack of support from peers and colleagues with 3 instances. The others category only one answer and that was unsure with 3 instances.

The main difference between the pre and post-workshop answers were that lack of resources is now the most commonly found category with 54 instances and low self-efficacy is next most common with 45 instances. The other category has decreased slightly down to 2 instances. The total number of instances has stayed roughly the same with 100 instances in the pre-workshop survey and 101 for the post-workshop survey. That the low self-efficacy category saw a decrease shows that the teachers felt more confident in the ability to teach CT after attending the workshop. They also expressed an increase in knowing about the lack of resources that exist for teachers to teach CT.

For the lack of resources category the top three answers have remained the same in the order, but all saw an increase. Not aware of the support, funding, activities, programs that are available increasing from 9 to 17 instances. Lack of time increased from 7 instances to 16, and lack support from peers or colleagues increased from 3 to 14. There was also a new answer on the list in the post-workshop survey of lack of availability of technologies and infrastructures with 7 instances.

The top three answers for the low self-efficacy category also stayed the same, but not in the same order. The most common answer remained as lack of knowledge and ability to understand computational thinking, with the number of instances decreasing from 36 to 18. The second most common answer pre-workshop was lack of effective teaching strategies, but post-workshop that is the third most common answer. It also saw a 50% reduction in the number of instances from 14 to 7. Lack of experience, practice and training moved up to the second most common practice post-workshop and the number of instances not changing from 13. This result shows that the teachers feel they have more knowledge, ability, and effective strategies, but they still feel they need more experience, practice, and training.

Bower et al. (2017) also conducted a survey about how to increase teacher confidence. To do this they asked the following question "What could help you to feel more confident about developing your students' computational thinking capabilities?" (Bower et al., 2017, p. 63). On the subject of the teachers building their confidence the pre-workshop survey had answers under three categories; resources and advice (61), formal professional development and training (24), and other (4). The top three answers for the resources and advice category are advice on effective teaching strategies with 36 instances, what resources are available to students and teachers with 9 instances, and advice on how to incorporate the concepts into the curriculum with 9 instances. The formal professional development and training category had two types of answer; attend courses and training with 16 instances and professional development with 8 instances. In the category of others, the top answer was try new things, take risks with 3 instances.

When the teachers were asked about building confidence post-workshop there were answers under three categories; resources and advice (74), formal professional development and training (38), and others (2). Therefore the total number of answers changed from 89 for the pre-workshop survey to 114 for the post-workshop survey.

For the resources and advice category the top three answers have changed completely and the top three answers in the post-workshop survey were not represented in the pre-workshop. The top three answers were providing more time to learn with 15 instances, get more relevant technologies and resources with 13 instances and provide examples, activities or lesson ideas with 12 instances. The top answer pre-workshop, advice on effective teaching strategies, decreased from 36 to 8 instances. This shows that the workshop had an impact in what the teachers considered needed for building their confidence. The fact that the answer advice on effective teaching strategies decreased by nearly 80% implies that the teachers felt they learnt some effect teaching strategies at the workshop.

The formal professional development and training category remained the same with only two answers and those two remained in the same order. The number did increase however. Attend courses and training increased from 16 to 23 instances, and professional learning increased from 8 to 15. This result indicates that even post-workshop the teachers still feel they need more chances to attend courses and receive training. There is also a new answer under the others category with the only answer now being learn with students.

During the process of writing this study the researcher's experience in many ways mirrored that of a teacher undergoing a professional development program. The researcher had preconceived constructs about the meaning of several CT concepts such as abstraction, decomposition and the use of models to understand a process. However, through the process of researching the existing literature on the subject of CT, and discussions with his supervisor, the researcher was able to develop and adapt his thinking about the subject. While it would be impractical for teachers to commit the time and resources to an in depth study as the researcher has done, teachers do need to receive some training in CT so that they can give their students a better learning environment in which to experience and master the practices of CT. The studies mentioned above (McLoughlin et al, 2019; O'Sullivan, 2002) show that if teachers are given the opportunity to have professional development on CT then they will have the expertise and confidence to introduce it into their classrooms.

2.5 Where can students learn CT outside the classroom?

There are a variety of places for students to have experiences of CT practices. Some of these places are examples of face-to-face learning between an instructor and student. However as Wing (2006; 2008) mentioned CT is something for everyone in their everyday lives. So students should also be able to experience CT outside the classroom. There does exist opportunities for students to experience CT online. These vary from the unguided visual programming platforms, such as, Scratch, Alice, and Blockly, to video guided platforms, such as, Khan Academy, or the Code Academy, to structured online courses often called MOOCs (massive open online courses).

The unguided visual programming platforms, such as, Scratch, Alice, and Blockly are ways of learning coding that uses pictures or symbol to portray the coding action rather than the lines of code in text-based coding. They are tools that give students the opportunity to develop projects either individually or in groups (Sylvan. 2010). One issue of this type of environment is that the learning is unguided and relies on the user to monitor their own progress. There have been studies to examine the performances of these types of platform and the results suggest that they do increase student comprehension compared to text-based programming (Brennan & Resnick, 2012; Weintrop & Wilensky, 2015).

The video guided platform, such as, Khan Academy, and Code Academy, provide the students with some guidance in form of short videos and tutorials. The Khan Academy is a non-profit organization that has over 5,000 videos that cover a variety of subject areas (Koeniger, 2013). After watching the video(s) the students are then, however, left on their own to solve problems and to assess their own progress. Studies into the effectiveness of these platforms show they can provide an opportunity to students to increase their competencies with CT, but it is reliant on student to be self-motivated (Morrison & DiSalvo, 2014).

Online courses, or MOOCs, are extremely popular and in some cases have enrollment numbers in the tens of thousands (Vihavainen et al. 2012). They are popular as they are granting an opportunity for learners from any place, background, and age to experience college level online courses for little to no cost (Haber, 2014). Studies show that MOOCs can have large dropout rates due to the difficulty for students to find courses that fit with their wants and needs (Raghuveer et al. 2014).

Chapter 3: Methodology

This study is a self-study and chronicles the researcher's journey from a CT novice to a CT expert. Self-study is a way of researching that can involve many different methods of research (Tidwell et al., 2009; Loughran, 2014). The benefit of a self-study approach is that it offers the opportunity for the researcher to experience these methods of research in a new frame of reference. Through this self-study research the researcher can develop their 'wisdom of practice' (Shulman, 2004). These new frames of reference and 'wisdom of practice' will give the researcher to space to study CT practices and consider how the it might be viewed differently from a science education viewpoint as opposed to a computer science viewpoint. Self-study has its focus on the practice itself. "This seems logical if one is aiming to change the way something is undertaken" (White & Jarvis, 2019, para. 5).

The focus of self-study on a practical application of the subject is one that the research was interested in pursuing. Teachers, on being asked to integrate CT into their curriculum, will take a practical approach (citation needed). As the purpose of this study is to layout a journey that teachers can follow then the approach must be what would be the best fit for them. A very important aspect of a self-study is the discussions that take place between acquaintances allowing for self-reflection (Trumbull, 2006). The researcher is indebted to his supervisor for providing the opportunities to talk and discuss about CT. Without these discussions and chances for self-reflection the research would have been bounded and not been as able to progress as far (Attard, 2014; North, 2015).

Many of the practices of CT are skills that have been the researcher has experienced before through their own studying in elementary school through to university and their work as a teacher. These skills, however, may need to considered in a different light, a CT 'light' to see how they need to be viewed when studying CT. Having no previous experience of CT the researcher started with a literature review of the concepts of CT. (1) Based on learnt knowledge, what kinds of CT practices can be found in STEAM programs and what description of CT in STEAM can be illustrated? (2) Through continued professional development, what additional or extended CT practices can be suggested to revitalize STEAM programs on the basis of the descriptions made above? (3) After coming towards the end of self-study journey what difficulties are encountered when developing a new STEAM module from the viewpoint of exposing the students to CT practices? (4) From the experience gathered during the self-study how can the researcher develop a professional development program to aid pre-service and in-service teachers' in their own journey to study computational thinking?

3.1 Flowchart of the Process of the Study's Research

Figure 5 below lays out the process that the researcher went through during the self-study of CT for this dissertation. The first box details how ten STEAM modules were analyzed for their CT content. The second box explains how those same ten modules' CT content was improved by a suggested activity from the researcher that would add missing or weakly exposed CT content. The third box describes how the researcher developed his own STEAM module that would expose students to CT practices. The fourth and final box illustrates how face validity was achieved by having two students use the CT_AT to analyze two STEAM modules and then discuss possible areas for improvement.

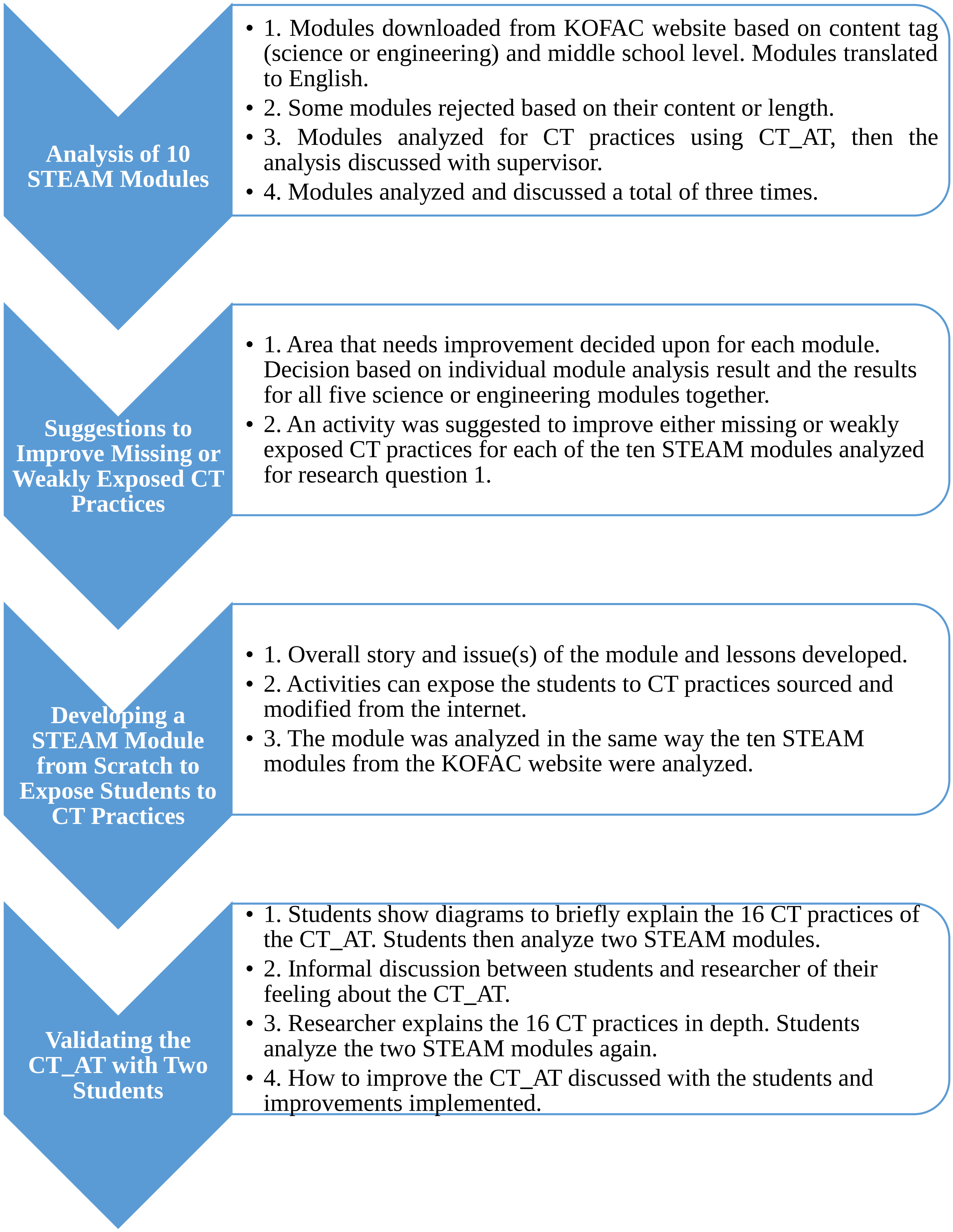


Figure 5. Flowchart detailing the research process step for this study.

3.2 Subject: STEAM programs to be analyzed

Two areas (science-focus, engineering-focus) were selected for this research. The reason why two areas were selected is that it was assumed there would be different patterns of description in using CT practices among science-focus and engineer-focus separately. If there is more science content, this is a science-focus STEAM program. If there is more engineering content, this is an engineering-focus STEAM program. The reason why the researcher selected two areas of STEAM is to compare CT practices use patterns in a variety of STEAM programs if any. The criteria which was used in selecting STEAM program are as follows. First, the researcher collected the data from the products of STEAM programs by KOFAC (Korean Foundation for the Advancement of Science and Creativity) where various types of STEAM programs can be downloaded (KOFAC, n.d.). KOFAC spends a considerable amount of funds on developing STEAM programs ever year. The selected STEAM programs (Table 7; Table 8) are introduced with the lessons in each module and titles and its overview.

The following describes the criteria and process by which the modules were selected from the KOFAC website. As discussed before it was decided to study science and engineering modules to compare the two disciplines for their CT content. The first criteria for the science modules was that they be either physics or Earth science based for the science modules. These two subjects were selected due to the background of the researcher. The researcher has a master degree in astrophysics and during both the undergraduate and postgraduate studying the researcher took some Earth science courses. The website was also searched for modules that were tagged as engineering based for the engineering modules.

Recent products of STEAM programs were selected from 2019 and five science focus STEAM and engineering STEAM programs were selected from middle school and high school levels by considering the researcher's background. This was again due to the background of the researcher and also what the researcher is interested in studying. The researcher has taught at the middle school level for 3 years in the past.

The KOFAC website's search function was used to find modules that fit the study's scope of science or engineering at the middle or high school level. The modules were then judged by their titles that they fit the scope. The researcher then went through the laborious process of translating the modules from Korean to English. The modules were put through the Google Translate service. The researcher's supervisor checked that the translation was accurate and then the researcher corrected the English.

After the modules were translated and checked they were assessed again for suitability. Ten of the modules past this test of suitability. There were several modules that did not meet the researcher's standards for suitability. One module was too short and was just one lesson worth of material. This was rejected as it would have involved comparing a single lesson to multiple lesson modules. Another module was rejected as it biology based rather than physics based. There was also another module that claimed to be physics based but the activities were almost completely about art projects to draw and colour pictures.

Table 7**.** The modules of STEAM program (science focused) selected in this study

Module	**#**	**Title**	**What the lesson is about.**
Science 1: We Will Tell You the Weather of the Universe	1	When the Sun Booms, the Earth is Bruised	Discussion of what disasters would happen if there was massive solar flares. Also data about sun spots and factors that can create space weather.
	2	Space Weather Forecast and Special Report through Observation of Solar Activity	Discussion of how to forecast space weather. Design an app to warn people about space weather.
	3	Creating a Space Environment Forecast Application	Further designing of the app. Analysis of the other groups' apps.
Science 2: Burning Ice, Gas Hydrate	1	Burning Ice, Gas Hydrate	Learn about what hydrate is and what it can be used for. Students make some solid hydrate. Compare solid, liquid, and gas fuels.
	2	How to Transport Gas Hydrates Safely?	Discussion on the energy imports into Korea and where to find gas hydrate around Dokdo. Watch a video on how to transport gas hydrates.
Science 3: Dokdo, Lonely Stone Island	1	Secret of the Birth of Dokdo	Discussion on the history of Dokdo's names and how it formed from an underwater volcano. Looks at 3 different types of rock and what rocks Dokdo is made of.
	2	What Dokdo Looks Like	Construct a topographical map of Dokdo.
	3	Dokdo, Our Land. Where are you?	Where is Dokdo and why is it Korean territory. Create a song for Dokdo.
Science 4: Silver Care Expert	1	Empathize with Grandma and Grandpa	Learn about the issues that elderly people have. Discussion about aging society and future occupations.
	2	Grandma and Grandpa Read Math	Survey to ask elderly people about their issues and visualize the data in graphs.
	3	I am an Advanced Silver Care Professional!	Investigation of various smart healthcare products. Students consider what product they would like to design and then make an ad for the product.
Science 5: Autonomous Cars	1	Autonomous Cars, it Wants to Know!	What devices would be needed for autonomous cars and how those devices work?
	2	Seen as Omnipresent "Autonomous Driving Technology"	What are some of the problems of autonomous cars and it asks moral/ethics questions.
	3	Autonomous Car, Solomon's Wisdom	Some more moral questions about who is responsible for accidents and questions about future laws that might be needed.

STEAM programs from KOFAC, where popular STEAM programs developed by the funds of KOFAC, are uploaded so that anybody can use them in and out of the classroom from K to 12. Those programs were developed, validated for reliability by experts before being uploaded to the KOFAC website.

Table 8**.** The modules of STEAM program (Engineering focused) selected in this study

Module	#	Title	What the lesson is about.
Engineering 1: Create Automated Devices for Safe Living from Disasters	1	What are Disasters and How Can We Overcome Them	Students learn about both man-made and natural disasters and how science and technology can be used to help protect people.
	2-3	Science and Technology Challenge for Disaster and Disaster Alarm	Students take a more in depth look at earthquakes and then design and create an earthquake alarm.
	4-7	Creating an Automated Disaster Alarm	The students look at different sensors and actuators that can act the same as different parts of the body. They are doing this to design their own automation device.
	8	An Exhibition Hall of the Classes Work	Students create an exhibition of the disaster automation device their group made. They then assess the devices made by other groups.
Engineering 2: Science Story at the Airport and Airplanes	1	Places to Get on the Plane	Student learn about prohibited items on airplanes, why they are prohibited and how security searches for the items. Finally there create their own metal detector.
	2	How Can I Float an Object	Students learn about the forces that act on airplanes. Then they build a hot air balloon.
	3	Airplane, the Secret of Center of Gravity	Students learn about center of gravity and how it effects the design of airplanes
Engineer 3: Where is the Fine Dust?	1	What and Where is Fine Dust?	Watch videos to discover what and 100 where fine dust is. Students investigate the levels of fine dust in their neighborhood.
	2	Can We Reduce Fine Dust?	Read about generation of fine dust while cooking. Experiment how to reduce fine dust from cooking.
Engineering 4: Ecological Drone Use	1	Fading Animals, Plants and the Future of Humanity	Students read about environmental destruction and animals' extinction. Also read about how technology can help restore ecosystems. Students learn how to control a drone.
	2	Ecological Models	Students create their own ecological model. Students learn how to program drones to survey ecological systems.

Engineering 5: Automata Bearing Safety	1	Pre-Learn About Automata	Watch a video on the different types of mechanical gears. Investigate the 7 safe area. Read about Smombies[3].
	2	Navigating Safety Incident Expressions of Tools	Students learn more about types of automata.
	3	Build a Safe Automata	Students think about the safety actions they would take when performing their own experiments.
	4	We are Safe Guards!	Students have an exhibition to show how they deal with different safety incidents.

3.3 Data Collection & Analysis

3.3.1 Modifying the CT analyzing tool

Two frames were mainly used to produce one reasonable CT analyzing tool (CT_AT) frame in this study; one is from Park & Hwang (2017) and the other is from Weintrop et al (2015). The protocols of CT practice by Park & Hwang (2017) were derived from three CT resources; The College Board (2013; 2017), 9 CT components by ISTE & CSTA (2011), and CT practice by NGSS (NGSS Lead States, 2013). The researcher compared those two frames (Park & Hwang, 2017; Weintrop et al., 2015), combined, modified, and redefine CT practices/protocols with examples. Major categories in CT were from the Weintrop et al (2015) frame and sub practices were compared and finalized with operational definitions with examples (Table 9). The modified CT_AT (which can be seen in the appendix) includes 5 protocols in Data Practice (DP), another 5 in Modeling and Simulation Practice (MS), and another 6 in Computational Problem Solving Practice (PS). The main categories were rooted from Weintrop et al. (2015) and concrete

[3] Smombies is the word used by the module. It is a combination of the words 'smartphone' and 'zombie'.

definitions and examples were from the frame (Park & Hwang, 2017) and the researcher's background. The samples of CT_AT in this study are as follows (Table 9).

Table 9. The sample practice of CT analyzing tool with definition and example

	Practice	Definition	Example of use
Data Practices	Collecting Data	Data collected through observation or measurement. CT is the use of systematic collection protocols and how they could be automated.	CT automation of the process allows for more data to be recorded, over greater time periods and with shorter intervals between measurements. Before CT the student could take measurements 5 or 6 times over the course of a 50 minute lab. Now with CT and setting up an Arduino the data could be recorded every minute and left running over night until class the next day. CT ability to handle bid data means that students can use historical data as well. For example, if they were studying climate change then they could collect data about precipitation and temperature for the previous 5, 10, or even 100 years.
	Creating Data	Using computational tools to generate data when investigating phenomena that cannot be observed or measured easily.	The student will be able to define computational procedures and run simulations that create data. The student can develop formulas including the important variables and run simulations on a computer, and so create the required data. This is different to former practices where a student would vary one variable and controlling the others. This approach, while useful in some situations, can create incorrect data. For example the student could input formulas on gravitation, fluid dynamics, etc. into a computational tool to generate data of galaxy evolution.

Data Practices	Manipulating Data	Reshaping the dataset to be in the desired or useful configuration. Includes the sorting, filtering, cleaning, normalizing, and joining of datasets.	This could be organizing data into alphabetical order or normalizing the data by showing its standard deviation from the mean. For example, a student could use a computational tool to rearrange in descending order the chemical composition of different air samples so that the differences between the compounds can be referenced easily.
	Analyzing Data	Looking for patterns, or anomalies, defining rules to categories data, and identifying trends and correlations. CT is especially useful in this era of big data.	Correlating the results of two variables to see if there is a link between them. CT is an effective tool for data analysis especially with the advent of big data. An example of data analysis would analyzing the data from thousands of weather station around the world to see if there has been any changes in the average precipitation and temperature.
	Visualizing Data	Graphs and charts (CT allows for more dynamic and interactive displays) to help communicate results.	CT makes it very easy to quickly and cheaply produce graphs and charts. For example a pie-chart could be created to show people the relative CO_2 production of various household activities. This makes it much easier for people to understand the relevant information. CT also makes it possible to make an interactive display that allows people to control variables and see the results. For example a display could visualize the effect of the temperature increase on polar ice and the resulting increase in sea-levels. People could see how increasing the temperature results in ice melt and sea-level rise.
Modelling and Simulation Practices	Using Computational Models to Understand a Concept	Computational models help students to form concepts of a phenomena. Gives students more control (than natural world) to investigate.	Using a computational model to observe the relationship between different methods of energy production (oil, natural gas, nuclear, or renewable) and the amount of CO_2 in the atmosphere. Formulas or animations can be used to help with understanding of the concepts for students. The model can be chosen by the students or it can be provided by the teacher.

	Using Computational Models to Find and Test Solutions	Computational models help students to apply concepts of a phenomena. CT allows for the possibility to test different solutions quickly, easily, and cheaply.	Having formed the concepts of the phenomena, computational tools allow students to find, test and justify a solution. For example, the students can quickly, easier, and cheaply test their possible solutions for which type of renewable energy production (solar, wind, tidal etc.) would be best for the intended location.
Modelling and Simulation Practices	Assessing Computational Models	Assessing how faithfully the model represents the phenomena. Students assess what assumptions have been made and how do they effect the behavior of the model. Could also be called validation of the model.	For example, students could assess whether the model of climate change is accurately depicting the phenomenon. Did the designer make assumptions about the effects of CO_2 levels on the greenhouse effect? The student can notice any limitations of the model. The student can assess suggested models before attempting to construct the model or assess models given to them by the teacher.
	Designing Computational Models	Making technological, methodological, and conceptual decisions. Characterize the relationship between components, and the data the model will produce. Also the make decisions about what assumptions need to be made.	An example of students designing a computational model would be designing a photo bioreactor. What shape should the reactor be, can mirrors be put around the reactor to increase efficiency, which species of algae would generate the most oil, and can the algae monitored automatically to make sure it is harvested at the best time? These are examples of decisions that need to be made in the design process.
	Constructing Computational Models	Can be the generation of new models or the adjustment of an existing model.	The actual implementation of the design choices. So 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.

Computational Problem Solving Practices	Preparing Problems for Computational Solutions	Reworking problems so that they can be solved by computational tools. Breaking the problem down into sub-problems and reframing them in such a way that an existing computational model can be used. If it is possible to design a modular solution it will result in a solution that is easier to reuse, repurpose, and debug.	For example, when tasked with investigating climate change the issue is very large and complicated. The student needs to break down the problem into more manageable parts. For example, with climate change there are many environmental factors but the student may decide to investigate two, precipitation and temperature.
	Programming	The writing of computer code either of a new program or modifying an existing program. Can be simpler to use languages like Python or more intensive languages like C++.	A real life example would be expressing the mathematical formulas governing climate change, climate change data inputs and outputs to be used to solve the problem in a way that the computer can understand. This means using conditional logic, iterative logic, recursions, and creating abstractions such as subroutines and data structures.
Computational Problem Solving Practices	Choosing Effective Computational Tools	Choosing a computational tool based on its range of use, adaptability, and whether the tool fits well with the planned data inputs and wanted outputs. Assessing the pros and cons of some computational tools to make the right choice for the requirements.	During an investigation of climate change the students might want to investigate the temperature. Which tool will fit the requirements? Will a mercury thermometer be best or does the student require a much more accurate laser thermometer? Will the digital laser thermometer be a better choice as it can automatically export the data to a computer? The student would decide that the digital laser thermometer was the better choice for accuracy and its ability to link to the computer.

Assessing Different Approaches / Solutions to a Problem	When faced with a choice between two models that will both provide the correct results other aspects like cost, time, durability, extendibility, reusability, and flexibility should be taken into account.	In the previous section (Choosing Effective Computational Tools) the student was making the choice of how to measure the temperature and choose the digital thermometer based purely on how well it fits the requirements of the investigation. Now the student has to consider real-life considerations. The digital thermometer is the better choice but it very expensive and so the student has to think again about which tool to use.
Creating Computational Abstractions	Bring the most important aspects of a phenomena to the front while relegating the less important aspects to the background. Abstractions are important for solving multiple problems that are structurally similar but differ in the details.	When attempting to investigate a problem like climate change there are too many variables to investigate them all. The student needs to decide which variables to concentrate on and which can be safely neglected.
Troubleshooting and Debugging	Methodically finding, isolating, duplicating, and rectifying computational tools that are giving unpredicted results.	Inspecting the computational tools to understand why the results produce are not matching what was expected. For example, after the student chooses the digital laser thermometer, but one of the thermometers is giving a very high temperature reading. The student needs to troubleshoot why. Is it an electrical fault or an error in the software? Or is the strange result due to human error in that the student is misusing the equipment?

The researcher discussed each item from theories and practical experience to be consensus for the content validity and its reliability.

The researcher's CT_AT is inspired by a few different groups, such as Weintrop et al (2015), ISTE & CSTA (2011), and NGSS (2013) among others. The main difference between the Weintrop et al (2015) taxonomy is the combining of the system thinking practices with other practices.

The researcher believes that system thinking is an important skill for students to acquire. "The ability to think systemically is an important habit of mind that supports not only the scientific background of the developing STEM workforce, but also future scientifically literate citizens. In a global society where future large-scale, scientifically based decisions will need to be made, it is important for the general populous to develop a systems thinking orientation toward the world" (Duschl and Bismark, 2013, p. 120). Weintrop et al (2015) however admits that system thinking is not fundamentally linked to CT and so can the system thinking practices present in Weintrop et al's (2015) taxonomy be combined with other practices? Further research is needed to confirm this is the case or whether the system thinking practices need to be included in the CT_AT.

The first three and fifth practice that Weintrop et al (2015) lists in the system thinking practices category are 'Investigating a Complex System as a Whole', 'Understanding the Relationships within a System', 'Thinking in Levels', and 'Defining Systems and Managing Complexity'. While these four practices are different from each other they are about considering aspects of a system and then contemplating what aspects should be considered as the whole system together, how different aspects of a system interact, what the macro and micro levels of a system are, and how to set the limit/boundary of a system. These practices can be folded into what is termed PS1 (Preparing Problems for Computational Solutions) and PS5 (Creating Computational Abstractions) in the CT_AT.

The fourth practice is 'Communicating Information about a System'. In the Weintrop et al (2015) paper it is defined effectively communicating information about a system so that is can be understood. This is similar to what students are doing when they perform the DP5 (Visualizing Data) practice. The visualizing of data is about presenting information so that it can be understood more easily. It is possible that the DP5 practice should be renamed to include verbal communication.

3.4 Collecting the Data

From the STEAM programs, the researcher used the CT analyzing tool (modified for this study) and counted the most exposed CT practices in each lesson of each module. There could be a few or a several CT practices in each section of lessons but the most exposed practice of CT in collecting the data was considered.

A very important procedure in the collection of the data was the learning process the researcher went through as part of the self-study of CT. Each module was analyzed three times with a discussion with the supervisor after each analysis. This discussion involved talking about any of the activities that the researcher had difficulty in categorizing and trying to come to a resolution about what CT practice was being demonstrated.

The example below (fig. 6) shows an activity from Science 1: We will tell you the weather of the universe. The activity is at the very start of the first lesson of the module and involves the students considering the effects of solar flares on the communication systems of Earth.

When the Sun goes Boom, the Earth is Bruised.

In the movie "Knowing", the human race is destroyed by massive solar flare explosions and weakening earth magnetic fields. In particular, there are scenes in which a plane crashed, why?

Enter 1 – What if all the communication devices stop suddenly?

1) Let's consider what kind of situations we are using wireless communication.
2) Imagine the various damages that can occur when a communication failure occurs.
3) Think about what might be the cause of a sudden communication failure.

Figure 6. Example of a misclassified activity from Science 1

The first time this activity was analyzed it was designated as PS1 (Preparing problems for computational solutions) as it was thought to be about the students decomposing the issue of the solar flares. However, after some discussion with the researcher's supervisor it was reclassified as PS5 (Creating computational abstractions). In the discussion it was talked about how the students are simplifying the issue of the communication failures. This simplifying is abstraction and therefore the activity was changed to be PS5. This change is an example of how the researcher's opinions on the differences between decomposition and abstraction evolved. The 'textbook' definitions of decomposition and abstraction were not difficult for the researcher to understand even at first. As discussed in table 9, decomposition is the breaking up of an issue into smaller more manageable parts, while abstraction is deciding what are the most important factors of an issue and must be considered while allowing less important factors to be safely neglected. During the first analysis the researcher picked up that the students were considering different situations and confused that decomposing the issue. Through discussion and self-reflection, however, the researcher came to the conclusion that the real point of the activity is for the students to consider what the most important reasons for the communication failures are.

The next example (fig. 7) of the researcher's learning process is a case where the researcher was at first unable to assign the activity as being a particular CT practice. The activity is in the third lesson of Science 5: Autonomous cars and involves the students considering two car accident situations and making a moral choice about who the car would choose to hit from two different options.

A crossroads of choice

If your vehicle is programmed differently in an unpredictable situation, which one would you buy?

If you have an accident that can't be stopped while driving with an autonomous car,

1. When there are several other pedestrians and one pedestrian on the road,

(1) Vehicle A bumps several pedestrians.
(2) Vehicle B bumps into a pedestrian.

The vehicle I chose is ( ), and the reason is ( ).

2. When there are elderly pedestrians and young children pedestrians on the road,

1) Vehicle A bumps into an elderly pedestrian.
2) Vehicle B bumps into a young child pedestrian.

The vehicle I chose is ( ), and the reason is ( ).

Figure 7. Example of a difficult to classify activity from Science 5

On the first analysis the researcher did not give this activity any designation for a CT practice, but flagged it for discussion with the supervisor. Initially the researcher was thinking that this activity demonstrated PS4 (Assessing different approaches / solutions to a problem), however, this conclusion was rejected. It was rejected as it was decided that the students are not actually comparing different approaches, but rather they are making decisions about what they think is the morally correct thing to do in a given situation. After much discussion and self-reflection it was decided that this activity demonstrates the MS3 (Assessing computational models) CT practice. This example is a demonstration of how the researcher's knowledge was developing through the self-study. During the first analysis the researcher had no idea about what CT practice to assign to the activity. It shows the development of the researcher to be confident enough to assign a practice on the subsequent analysis.

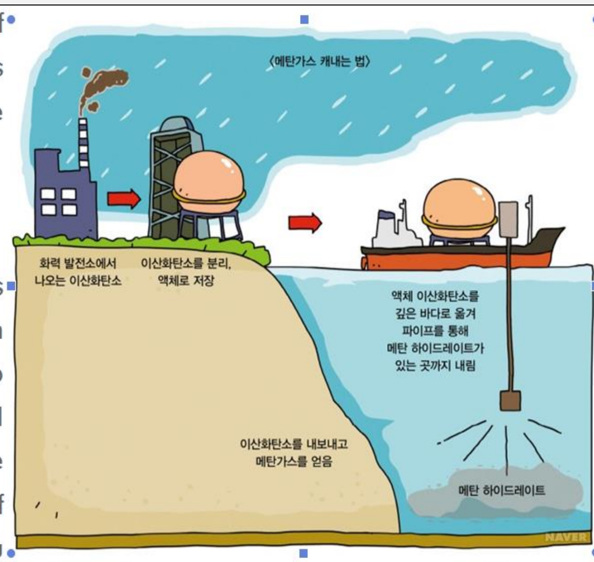
The format of the samples is like this, the first line of the table gives the practice that will showcased and the module the example is taken from. There is then a screen shot of the activity that includes the practice. The different practices are highlighted in a black box and given a number reference. The next line (labelled context) of the table gives some background to activity to give the reader an idea of the setting. In the final line of the table (shaded in grey) details the practices highlighted in the screen shot.

Table 10 shows an example of the DP1 (Collecting Data) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 10. Sample of the collecting data (DP1) practice for this study

DP1	Science 2: Burning Ice, Gas Hydrate

Moreover, if methane explodes in the process of obtaining methane gas, it can cause serious environmental pollution or be a threat to the ecosystem.



How to mine gas hydrate

So how do you use gas hydrates? The solution to this is surprisingly from carbon dioxide. If you put carbon dioxide, which has a molecular structure similar to methane gas, next to the gas hydrate, methane will escape from the ice and carbon dioxide will be replaced instead. It's a revolutionary way to get rid of greenhouse gases and get clean, clean energy. You can't develop a gas hydrate for the East Sea right now, but are you really confident that the energy source of the future underneath our country's oceans will be substantial? You can use domestic fuel to get out of energy poverty that doesn't drop a drop of oil.

Refer to the above article to summarize the gas hydrate. **How is gas hydrate made?** ① **What is the appearance of gas hydrates?** ②
Context: (Lesson 1/2). This is at the beginning of the first lesson and it is about introducing the students to the topic of gas hydrate. There is some more information before this and some more questions after.
① **DP1:** In this activity the students reading the information in the preceding article and writing a summary to answer the question of "How is gas hydrate made?" This is considered to be an example of DP1 as the students have to collect the information from the article. ② **DP1:** This activity is very similar to ① in that the students are reading from the article but this time answering the question "What is the appearance of gas hydrates?" This is also considered to be DP1 as the students are again collecting information from the article.

Table 11 shows an example of the DP2 (Creating Data) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 11. Sample of the creating data (DP2) practice for this study

DP2	Science 4: Silver Care Expert
Write five words that come to mind when you are my grandmother or grandfather. ① Write down what you think is difficult about your grandmother and grandfather's economic, physical, and surrounding circumstances. ②	

Context: (Lesson 1/3) 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.
① **DP2**: In this first activity, the students need to write down five words that come to mind when thinking about their grandparents. This activity is considered as DP2 because the students are creating the data to be used in the survey. ② **DP2:** This activity is direction after activity ①. This activity is similar to ① but this time the students are considering the economic, physical, and surrounding difficulties of elderly people. Just as with ① this is considered as DP2 because the students are creating data to be used in the survey.

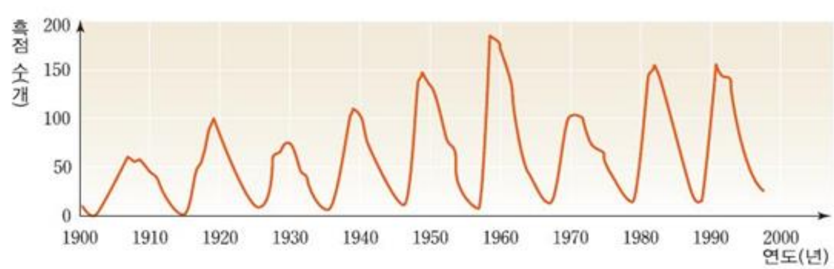
Table 12 shows an example of the DP3 (Manipulating Data) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 12. Sample of the manipulating data (DP3) practice for this study

DP3	Science 1: We Will Tell You the Weather of the Universe

Sunspots and Solar Activity

The following is an observation of sunspot numbers over the last 100 years.



[Source-Venus Textbook Science 3]

1) Find the year with the maximum number of sunspots and record it in the table below. ①

division	1	2	3	4	5	6	7	8	9
Maximum year									
interval									

Context: (Lesson 1/3) This is the start of part two of lesson 1, called "Is there weather in space?" This is the first activity the students do after theoretical and hypothetical exercises and the first time they are presented with real data.
① **DP3:** This activity sees the students taking the data of the relationship between sunspots and solar activity from the graph and changing it into figures in the table. This is considered as DP3 as the students are manipulating the data from graphic form to numerical form in the table.

Table 13 shows an example of the DP4 (Analyzing Data) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 13. Sample of the analyzing data (DP4) practice for this study

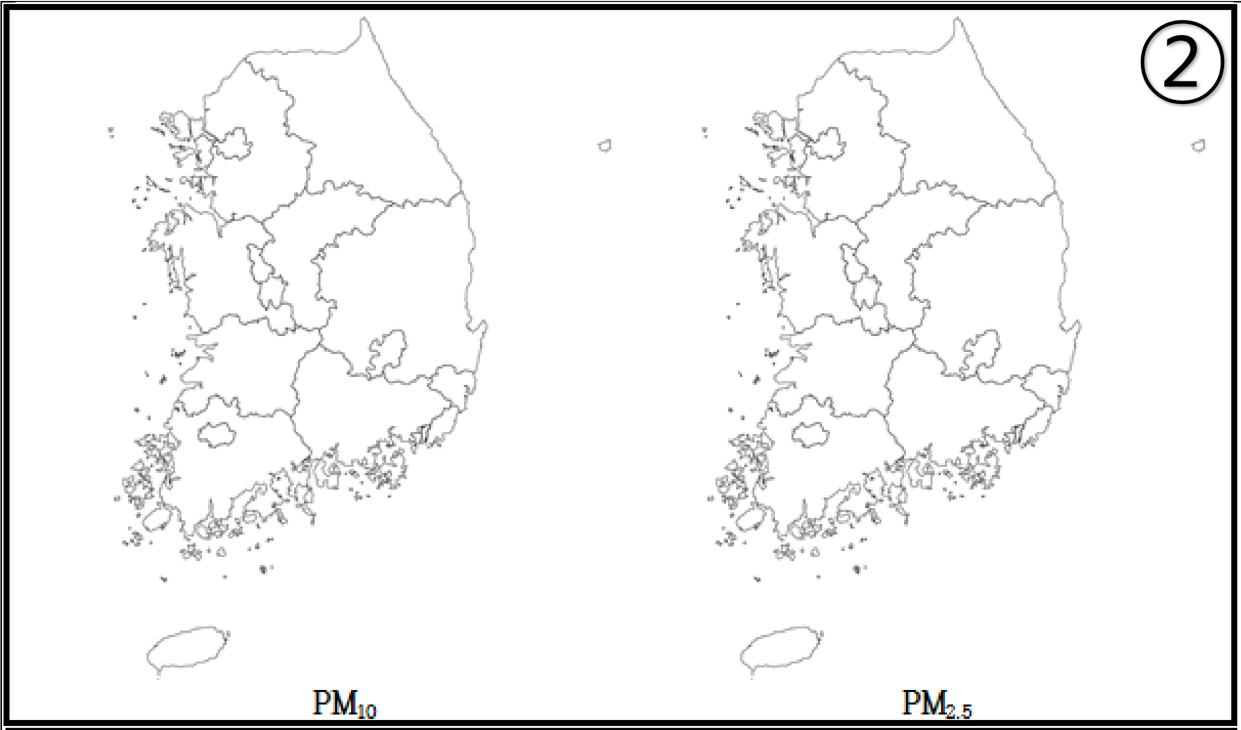
DP4	Engineering 3: Where is the Fine Dust?

☑ Check the average daily atmospheric information (PM10, PM2.5) for each real-time trial and color by region according to the grade.

	Seoul	Busan	Daegu	Incheon	Gwangju	Daejeon	Ulsan	Gyeonggi	Gangwon	Chungbuk	Chungnam	Jeonbuk	Jeonnam	Sejong	Gyeongbuk	Gyeongnam	Jeju
PM_{10}																	
$PM_{2.5}$																	

①

Forecast content	ranking (㎍/㎥)			
	Good	Usual	Bad	Very bad
fine dust PM_{10}	0~30	31~80	81~150	More than 151
fine dust $PM_{2.5}$	0~15	16~50	51~100	More than 101



① Is there a difference in fine dust concentration in each region? ③

Context: (Lesson 1/2) This is the nearing the end of the long first lesson and is part of the 'Classroom Mission: What is the Concentration of Fine Dust in My Neighborhood?' The students are investigating data from the internet before starting their own experiments of fine dust in their neighborhood.

① **DP1:** In this activity the students are collecting data from the airkorea website to find the fine dust concentration in different region around Korea. They collect the data from the website and input it into the table. This activity is considered DP1 as the students are collecting data.

② **DP5:** In this activity the students are taking the data in the table collected in ① and making a visual representation by colouring the map to show the fine dust concentration. This is considered as DP5 because the students are showing the data in a visual medium of the coloured map.

③ **DP4:** In this activity the students are analyzing the data they collected in activity ①. The students need to analyze that data to see if there is a difference in the fine dust concentration. This activity is considered to be DP4 as the students are doing an analysis of data.

Table 14 shows an example of the DP5 (Visualizing Data) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 14. Sample of the visualizing data (DP5) practice for this study

DP5	Engineering 2: Science Story at the Airport and Airplane
The aircraft moves faster on the wings. The faster the movement of the gas, the farther the molecules are, the smaller the pressure. The plane is forced upward by the pressure difference. To make this effect even bigger, the shape of the airplane's wing is modified. Consider the angle of attack, another cause of lift. Angle of attack is the angle that the wing of the aircraft makes with the horizontal plane. Larger angles of attack provide greater lift, but also increase drag, which impedes propulsion. Here is a picture of two wings with different angles of attack. In each case, let's graphically describe the force that the wing receives from the air and the resulting lift. ① 	
Context: (Lesson 2/3) This is located in the middle of both the module and lesson 2. It is the final part of activity 3 'Power on the Plane', during which the student learn about the different forces that act on the wings of airplanes. The next activity is 'Create a Hot Air Balloon'.	
① **DP5:** In this activity the students need to use the information they learnt earlier in the activity to make a visual representation of the forces acting on the wing. They do this by drawing arrows on the diagrams of the wings to show the direction of the forces. This is considered to be DP5 as the students have to make a visual representation of the forces.	

Table 15 shows an example of the MS1 (Using Computational Models to Understand a Concept) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 15. Sample of the Using Computational Models to Understand a Concept (MS1) practice for this study

MS1	Science 4: Silver Care Expert
1. Choose a group of similar items for the elderly.	
	
Eye Team: Glaucoma, Cataract Glasses	Back Team: Foldable Back guard
	
Leg Team: Knee, Ankle Sandbag	Arm Team: Wrist, Elbow, Gloves

With the object of your choice, you can complete the following missions:

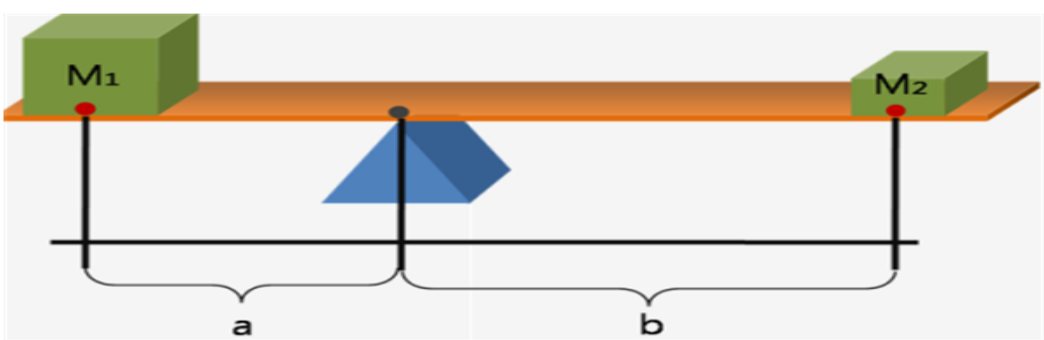
team	mission
Eye team	**- Thread the needle** **- Read the newspaper out loud** **- Walk without stepping on the line** ①
Back team	**- Take out 5 things high up** **– Squat and get up 10 times**
Leg team	**- Go up and down stairs from the first floor to the third floor** **- Crouch and sit up 10 times**

Arm team	**- Line up 10 small things (blocks) on high ground** **- 3 small paper dolls cut with scissors**	①
Context: Lesson 1/3. This is part of the first lesson where the students are ask to consider what life would be like as an old man.		
① **MS1:** In this activity the students are trying to complete missions of everyday activities while wearing different equipment that is designed to hinder their movement. The students are doing the experiment so that they can understand the difficulties of being an elderly person. This is considered MS1 as the activities are the students modelling being elderly in order to understand the concept.		

Table 16 shows an example of the MS2 (Using Computational Models to Find and Test Solutions) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 16. Sample of the Using Computational Models to Find and Test Solutions (MS2) practice for this study

MS2	Engineering 2: Science Story at the Airport and Airplane
3. If you look at the figure and want the lever to equilibrate, build a relationship between the weight of the lever and the position of the weight (the distance from the center of the lever).	



①

4. When the lever is in equilibrium, which is the center of gravity of the lever? What happens to the lever if it is not balanced? ☞
Context: (lesson 3/3) This is part of the first action of lesson 3 called 'Use the Weights to Centre the Weight of the Lever'. The students are learning about the concept of the centre of gravity.
① **MS2:** With this activity the students are find the relationship between the weights and the distance of the weights to the centre lever. This is considered to be MS2 as the students are testing their understanding of centre of gravity.

Table 17 shows an example of the MS3 (Assessing Computational Models) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 17. Sample of the Assessing Computational Models (MS3) practice for this study

MS3	Engineering 1: Create Automated Devices for Safe Living From Disasters and Disasters
• Pros and cons of the work: ①	
• Benefit: ③	
• Improvement ideas: ②	
Context: (lesson 8/8) This is the final lesson of the module and is called 'What is Exhibition Hall Learning?' The idea of the lesson is for the students to show their work to the other students and for them to judge how to improve each other's' work. However, first the students create a work outline about their own work.	
① **MS3:** This activity is part of the 'Opening Thoughts' which begins lesson 8 called 'Creating a Work Outline'. The students are creating an overview of the automation device that their groups made. Activity ① is the students considering the pros and cons of their group's automotive device. This activity is considered as MS3 because the students are making an assessment of their model. ② **MS3:** This activity follows activity ① and involves the students examining the benefits of their automotive device. This activity is considered as MS3 because the students are making an assessment of their model. ③ **MS3:** This activity is the final activity of the 'Opening Thoughts'. The students will contemplate ideas for how to improve their device. This activity is considered as MS3 because the students are making an assessment of their model.	

Table 18 shows an example of the MS4 (Designing Computational Models) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 18. Sample of the Designing Computational Models (MS4) practice for this study

<table>
<tr><th>MS4</th><th>Science 1: We Will Tell You the Weather of the Universe</th></tr>
<tr><td colspan="2">📖 Basic design of space weather paper prototype ①

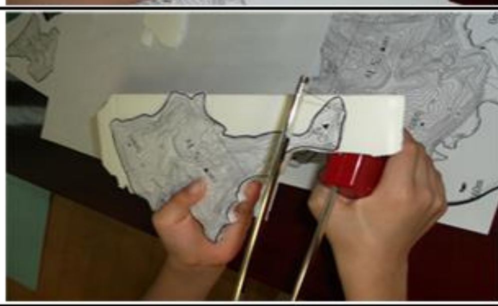
Let's design a smartphone application paper prototype based on information related to space weather.

What is the Smartphone Application Paper Prototype?

Even if you don't have coding skills, if you have an idea for an app or program, you can simply draw the program you want to draw on paper and create a video that you can turn into a movie to show a working model of the application. It is one of the most beneficial methods in that it is low cost and easy to find and reflect the problem.</td></tr>
<tr><td colspan="2">Context: (lesson 2/3) This is the last activity of lesson 2. The students are beginning the design of an app to warn about space weather. The students make a paper based app design.</td></tr>
<tr><td colspan="2">① MS4: In this activity the students are beginning the process of designing their app by deciding on such things as title, who would use the app, the concept, and the content. This is considered to be the MS4 practice as the student are designing their model.</td></tr>
</table>

Table 19 shows an example of the MS5 (Constructing Computational Models) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 19. Sample of the Constructing Computational Models (MS5) practice for this study

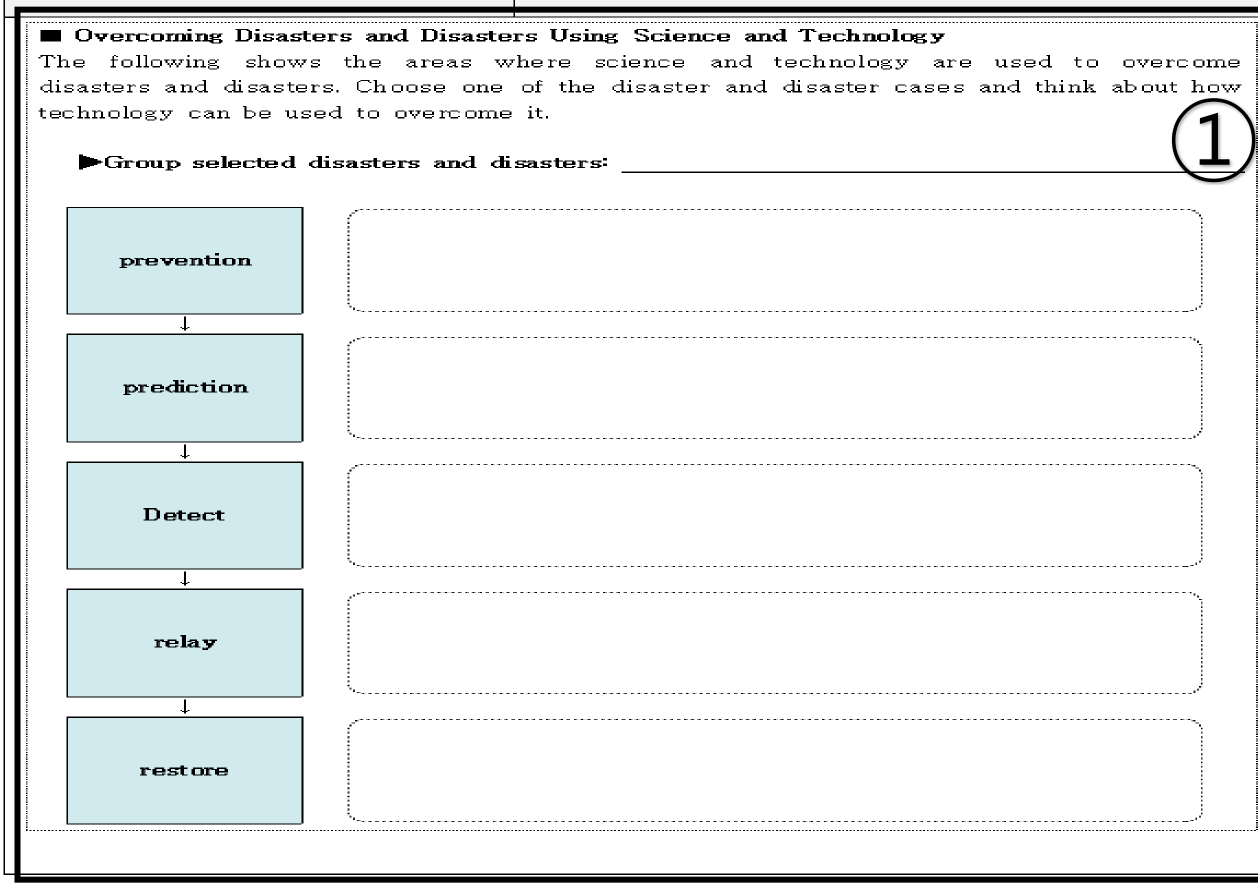
MS5	Science 3: Dokdo, Lonely Stone Island
	① ▪ Crop Topographic Height – Cut the topographic map of the 20-meter west and east road provided by height – In the group, it is good to make a three-dimensional map by dividing the height to be produced for each individual.
	▪ Pasting to Topographic Woodlock – Attach the topographic map, cut by height, to the woodlock using glue. – One piece of four-fold Wood Rock can be used.
	▪ Trim Wood Rock by Height – Use a wood lock cutter to cut the wood lock by height. – Wood lock cutters use electricity and have heating wires, so pay attention to safety.
	▪ Stacking Woodlocks to Fit Position and Height – Accurately stacks woodlocks to determine heights and topographic map locations, and complete stereoscopic maps.
	▪ Decorate the completed Dokdo stereo map – Each of the completed Dokdo 3D maps will be creatively decorated using various things such as colored pencils and colored paper. – You can decorate at any time during or after the completion of the three-dimensional map.
source : http://cy.cyworld.com/home/21399383/post/55E59BAC9A55A594B5828401	

Context: (lesson 2/3) This is the last activity of lesson 2. The lesson is about the appearance of Dokdo. The model is part of an attempt to install a sense of nationalism in the students about Dokdo.	
① **MS5:** 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.	

Table 20 shows an example of the PS1 (Preparing Problems for Computational Solutions) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 20. Sample of the Preparing Problems for Computational Solutions (PS1) practice for this study

PS1	Engineering 1: Create Automated Devices for Safe Living From Disasters and Disasters


■ Overcoming Disasters and Disasters Using Science and Technology
The following shows the areas where science and technology are used to overcome disasters and disasters. Choose one of the disaster and disaster cases and think about how technology can be used to overcome it.

▶Group selected disasters and disasters: ______

Context: (lesson 1/8) This is in the first lesson of the module. Before this the student are discussing natural and man-made disasters. This activity is introducing the idea of using science and technology to overcome disasters.
① **PS1:** In this activity the students are breaking down the issue of how to overcome a disaster into the sub-problems of prevention, prediction, detect, relay, and restore. This is considered to be the PS1 practice as the students have to decompose the issue into the small parts in order to make the issue solvable.

Table 21 shows an example of the PS2 (Programming) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 21. Sample of the Programming (PS2) practice for this study

PS2	Engineering 1: Create Automated Devices for Safe Living From Disasters and Disasters

4) Enter the following Arduino code into the IDE, upload it to Arduino, and check if it works by shaking the alarm.

①

파일 편집 스케치 툴 도움말

sketch_sep18a §

```
void setup() {
  Serial.begin(9600);
  pinMode(3,INPUT);
  pinMode(4,OUTPUT);
}

void loop() {
  int earthquake = digitalRead(3);
  Serial.println(earthquake);

  if(earthquake==0) digitalWrite(4,HIGH);
  else digitalWrite(4,LOW);

  delay(2000);
}
```

Context: (lesson 2-3/8) This is 2-3 lesson section and is here the end of that section in an activity called 'Create an Earthquake Alarm'. The students are using an Arduino.
① **PS2:** In this activity the students need to program the Arduino to act as an earthquake alarm. They do this by entering the code and then uploading it. This is considered to be the PS2 practice as the input of the computer commands is programming the Arduino to notify the user when it is shaken.

Table 22 shows an example of the PS3 (Choosing Effective Computational Tools) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 22. Sample of the Choosing Effective Computational Tools (PS3) practice for this study

PS3	Engineering 4: Ecological Drone Use

①

4-3 Explore ecology around us

Think about the eco-environment model you want to express using the materials. let's see.

Material to be picked up (excluding disposables): Carrara, Blue Moss, Colored Paper, Tinfoil, Anvil, Cellophane Paper

Three ingredients from the individual or group:

The element you want to create	Expression method	Remarks (material)

Context: (Lesson 1/2) This activity is last activity of the first lesson. This lesson is about environmental destruction and animals' extinction. The students learn about how technology can help restore ecosystems. Students learn how to control a drone.

① **PS3:** This activity is a part of a larger activity to design and create an ecological model. This activity is the students deciding what materials they require in order to construct the different elements of the ecological model. This is considered PS3 as the students are choosing the materials based on how effectively they will represent the element.

Table 23 shows an example of the PS4 (Assessing Different Approaches / Solutions to a Problem) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 23. Sample of the Assessing Different Approaches / Solutions to a Problem (PS4) practice for this study.

PS4	Engineering 5: Automata Bearing Safety

<View contents summary> ①

7 safety zones	What safety incident did you represent?	What is the best practice?
Life safety		
Traffic safety		
Drugs, cyber addiction		
Violence and Personal Safety		
Disaster safety		
Occupational Safety		
first aid		

Context: (lesson 4/4) This is midway through the final lesson of the module. This module is about exhibition hall, i.e. the students have to display and show their work to other students. The students have been designing a safety appliance.
① **PS4:** In this activity the students have to look at the work of other students to decide which group was best in the seven different safety zones, life safety, traffic safety, drugs and cyber addiction, violence and personal safety, disaster safety, occupational safety, and first aid. This is considered PS4 as the students have to assessing and the different approaches and solution developed by the other groups.

Table 24 shows an example of the PS5 (Creating Computational Abstractions) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 24. Sample of the Creating Computational Abstractions (PS5) practice for this study

PS5	Science 5: Autonomous Cars
How can an autonomous car drive itself? ① Do you know the coined term "Smombie"? It is a compound word of smartphone and zombie. It means a person walking on the road while watching a smartphone. 'Smombie' is also called a time bomb because it walks slowly and doesn't look around. Why? ② What should you do if you find a sinkhole in front of your eyes while walking on the road with a friend? Naturally, it will be avoided with safety in mind. How do our bodies collect various information about road conditions, such as obstacles, when we walk? How will the information we collect be determined and acted upon? ③ Considering the organs of our bodies, let's design and implement an autonomous car to drive on its own.	
Context: (lesson 1/3) This is at the start of the module and is part of the students being introduced to the topic of autonomous cars.	
① **PS5:** In this activity the students have to think about the dangers the Smombie will face as they walk around without looking around. This is considered PS5 as the students have to simplify the problem of the Smombies. ② **PS1:** In this activity the students are breaking down the issue of the body collecting information about our surroundings. This is considered to be the PS1 practice as the students are decomposing the issue into its various parts. ③ **PS5:** In this activity the students are deciding how to design an autonomous car to replicate the functions of the organs of the body chosen in ②. This is considered to be PS5 as the students have to simplify the functions of the organs.	

Table 25 shows an example of the PS6 (Troubleshooting and Debugging) CT practice. The sample shows how the researcher analyzed the content of each lesson to see what protocols of CT practices found.

Table 25. Sample of the Troubleshooting and Debugging (PS6) practice for this study

PS6	Engineering 5: Automata Bearing Safety
생각 모으기 Collect thoughts ① 2. After completing an automata representing safety accidents, think about what went wrong during the production process and summarize what the problem was and how it was solved. What was the problem? | How did you solve it?	
Context: (lesson 3/4) This is one of the steps involved in the creation of a safety automata. The students are given some materials and asked to choose a safety accident for a type of movement.	
① **PS6:** In this activity the students are asked to think about problems that arose during the production process and how the students went about solving the issues. This is considered to be the PS6 practice as the students had to find a solution to any problems that occurred. This is called troubleshooting.	

3.5 Data Analysis

All counted protocols of CT practice from CT analyzing tool in this study were transferred to the bar graph, viewable in the results section, so that the pattern of CT uses could be read easily in order to describing the uses of CT in each module.

3.5.1 How the STEAM program was designed and why?

The first decision to be made by the researcher was the over-arching story of the module. The decision to have the module based around space is some aspect was made based on the researcher's background. Both the researcher's undergraduate and master's degrees were astrophysics and so space and the study of space has been a personal interest for the researcher since an early age. The idea of visiting and living on another planet has also fascinated the researcher for a long time and so the decision to base the module around that.

It is also important for STEAM programs to face and talk about an issue affecting society and one of the biggest issues that needs to be addressed by humanity is that of climate change. Therefore the over-arching story of the program is how climate change may make the Earth uninhabitable for humans and that to survive humans may have to escape and make a home on another planet.

With the story of the program decided the researcher then started to design and map out the activities. This was always approached with the attempt to maximize the instances of CT practices that the students would encounter. The program went through many reworks from a first basic sketch before reaching the finished article. There was many times when activities were changed, deleted, or added so that more CT practices were present and also to strengthen CT practices that were weakly exposed or missing from earlier drafts.

3.6 Constructing Face Validity

In order to construct the face validity of the CT_AT two graduate students were asked to analyze two of the STEAM modules twice. Both of the graduate students are pursuing their PhD qualifications in science education and both also have backgrounds in science. One of the students is female and one is male. The female's background is in biology and the male's background is in Earth science. They both speak English well, however, the female's language level is higher than the male's. The two students agreed to be a part of the study and signed a consent form for their thought and opinions to appear in this dissertation.

It was decided to do informal conversational face-to-face interviews with the participants as this would allow for the greatest freedom for the interviewees and researcher to reach a consensus (Hollway & Jefferson, 2000). The final interview with the female student was done over the telephone, at the request of the interviewee due to concerns with COVID-19. This does reduce the ability of the researcher to observe any social clues, such as, body language, but using the telephone was the only option (Opdenakker, 2006).

For the first stage, the students were presented with three diagrams (Figures 31, 32, and 33). The diagrams detail the thought processes that the researcher went through when analyzing the STEAM modules himself. There are some general pieces of information written in black. This is some information about how commonly the researcher found the practice. Next, there is some hints and suggestions that could be useful for the students to be more confident about choosing what practice to assign to an activity. The final pieces of information are written in red. This information is some warning and things to watch out for when analyzing STEAM modules.

The students were given no further information than what could be found on the diagrams. This was to see how the students would analyze the modules with minimal input from the researcher and to provide a baseline from which to see if discussions with the researcher changed their opinions of what CT practices the activities display.

For the second stage, the students were presented with a copy of table 9. This table gives a detailed definition of each CT practice and an example of how this CT practice could be used in the science education classroom. The researcher went through this table with the students and explained the thoughts and opinions of the researchers as to what each CT practice entails and why the givens examples are that particular CT practice and not another. The researcher also explained what to watch out for when analyzing the modules to provide them with the hindsight and the benefit of the experience that the researcher developed during the self-study.

After each stage the researcher and interviewees talked about the feeling and thoughts that the interviewees had about analyzing the modules. Topics the researcher and interviewees talked about difficulties and confusion that the students experienced when analyzing the modules.

It would have been too much to ask the two students to analyze all 10 of the STEAM modules that the researcher analyzed. It was therefore decided to ask the students to analyze two modules, one of the science based modules and one of the engineering based modules. In order to have the student encounter as many of the CT practices as possible they were given the module that the researcher considered to have the greatest range of practices based on the researcher's analysis. The students were therefore given 'Science 4: Silver Care Expert' and 'Engineering 1: Create Automated Devices for Safe Living from Disasters'.

Chapter 4: Results

In this chapter the results to the three research question will be presented. The three research questions were as follows:

1. Based on learnt knowledge, what kinds of CT practices can be found in STEAM programs and what description of CT in STEAM can be illustrated?
2. Through continued professional development, what additional or extended CT practices can be suggested to revitalize STEAM programs on the basis of the descriptions made above?
3. After coming towards the end of self-study journey what difficulties are encountered when developing a new STEAM module from the viewpoint of exposing the students to CT practices?
4. From the experience gathered during the self-study how can the researcher develop a professional development program to aid pre-service and in-service teachers' in their own journey to study computational thinking?

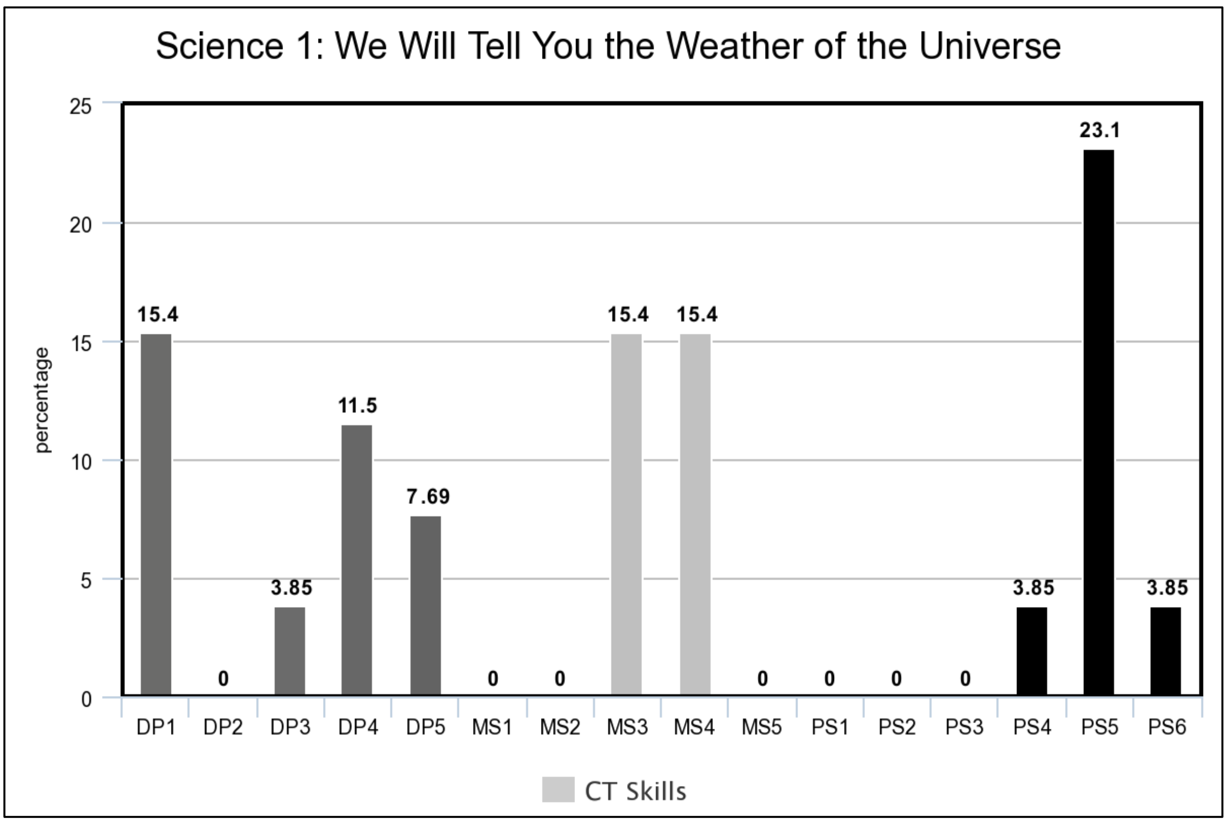
4.1 Results 1: Analyzing CT Practices

4.1.1 The characteristics of CT practices in STEAM lessons

In this section the researcher will answer the first research question to determine which CT practices are present and the proportionality with which they are found in the STEAM modules. The modules were analyzed using the approach described in chapter 3, methodology. The five selected science focused STEAM modules and five engineering focused STEAM modules were analyzed and then the results of the science STEAM modules were collated and also the engineering modules were collated.

4.1.1.1 Science-focused STEAM modules

The results for the five science focused STEAM modules are as follows. For each module there is a figure of a graph showing the pattern of CT practices uses in the STEAM module. There is then an interpretation of the CT uses. Fig. 8 shows the pattern of CT practices in science 1 STEAM module, whose title is ‘*we will tell you the weather of the universe’*.



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 8. The CT pattern of the 1st Science STEAM program and its description

A total of 26 computational practices were found in this module. There were 10 (38.5%) Data Practices, 8 (30.8%) Modeling and Simulation Practices, and 8 (30.8%) Computational Problem Solving Practices. So the skills found were evenly spread out between the three areas.

The most commonly found skill was PS5 (Creating Computational Abstractions) with 23.1% or 6 / 26 skills found in the module. All 6 instances were found in the first lesson. This is due to abstraction being a necessary step for students to come to understand a topic. They have to decide what are the important factors to consider and what can be confidently be ignored. An example from this module would be the exercise where the students are asked to consider what might be the cause of a communication failure with wireless equipment and what might be some possible damages. The joint second most found were DP1 (collecting data), MS3 (Assessing Computational Models) and MS4 (Designing Computational Models) all with 15.4% or 4 / 26. An instance of DP1 found in this module is the designing of a space weather warning app. On paper, the students have to make decisions such as the app name, who is the app aimed at, and the contents. There 7 examples of skills that recorded no instances. One of those PS1 (Preparing Problems for Computational Solutions) is in many cases found before MS4 (Designing a Computational Model) as it is considered a necessary step to prepare the problem before design the model.

Below (Fig. 9) is an example from this module of PS5 (Creating Computational Abstractions) would be the exercise where the students are asked to consider the movie “Knowing”. The students have to decide what important parts of the film explain the destruction and damages caused by the solar flares.

When the Sun goes Boom, the Earth is Bruised.

In the movie "Knowing," a situation in which humanity is destroyed due to a large-scale solar flare explosion and the weakening of the Earth's magnetic field. In particular, there is a scene in the movie where an airplane crashes. What was the reason?

Enter 1 – What if all the communication devices stop suddenly?

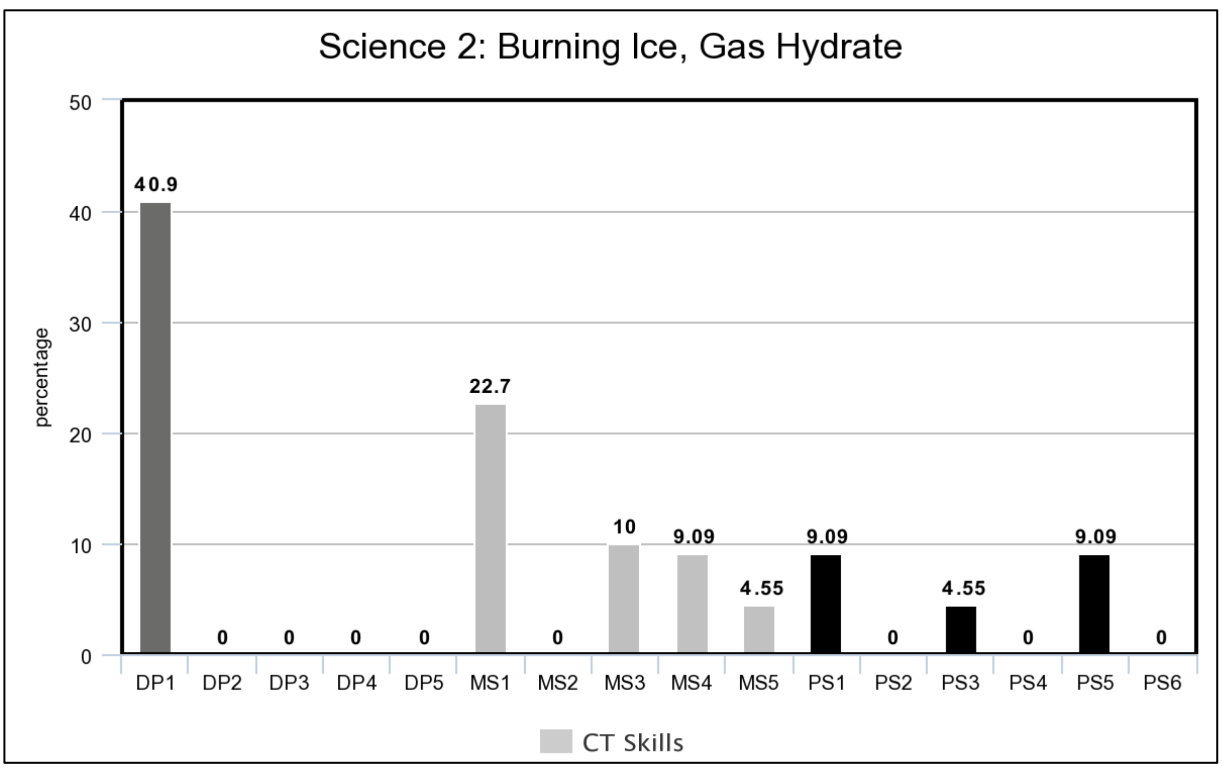
1) Let's consider what kind of situation we are using wireless communication around.

2) Imagine the various damages that can occur when a communication failure occurs.

3) Think about what might be the cause of a sudden communication failure.

Figure 9. An example of PS5 from the 1st Science STEAM program

The pattern of CT practices in science 2 STEAM program is displayed, whose title is '*burning ice, gas hydrate'* (Fig. 10).



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 10. The CT pattern of the 2nd Science STEAM program and its description

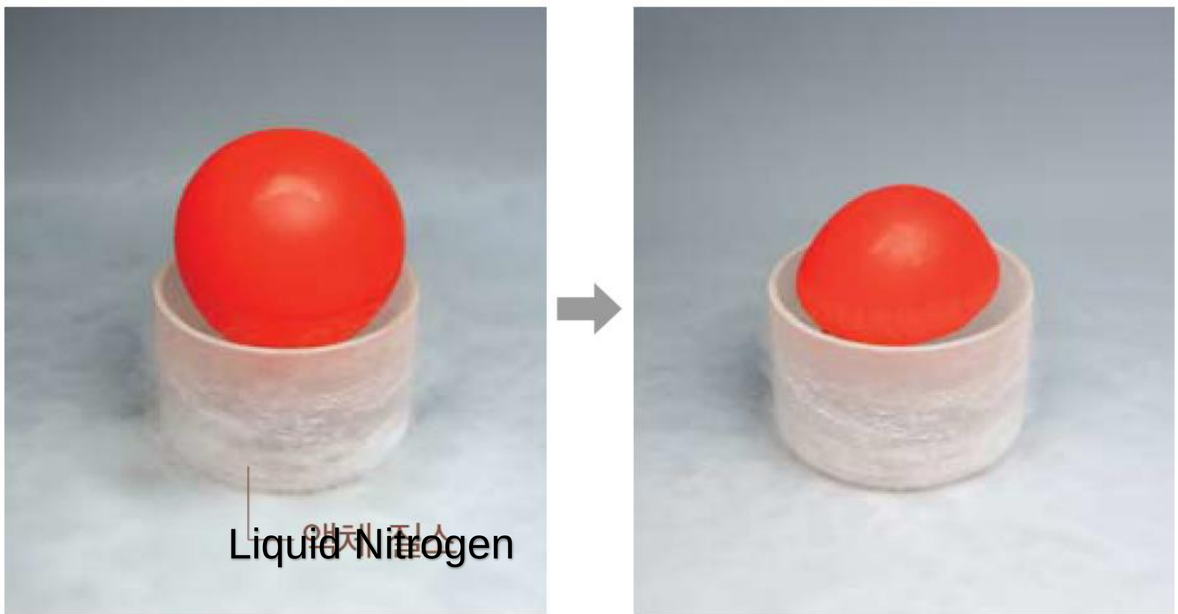
There were a total of 22 practices found in this module, 9 (40.9%) Data Practices, 8 (36.4%) Modeling and Simulation Practices, and 5 (22.7%) Computational Problem Solving Practices. So for this module there was less Computational Problem Solving Practices found.

The most commonly found skill was DP1 (Collecting Data) with 40.9% or 9 / 22 practices found in the module. 8 of the 9 instances were found in the first lesson. This is because the students were presented with a great deal of data by the teacher to give them an introduction into what is probably an unfamiliar topic. An example of this is the students had to read the information about gas hydrate to answer questions, such as, *"How is gas hydrate made?"* and *"What are the benefits and disadvantages or gas hydrate?"* The second most found was MS1 (Using Computational Models to Understand a Concept) with 22.7% or 5 / 22. This is due to the fact that the students perform 5 different activities aimed at helping the students to grasp the concepts. One of those activities was to make a molecular model (ball and stick model) of a gas hydrate molecule surrounded by 20 water molecules. This activity gives the students an understanding of the concept of a stable gas hydrate molecule. There 9 examples of practices that recorded no instances. One of those was DP4 (Analyzing Data) was expected as the students collect so much data, but do not make any analysis, they just answer the given questions.

Below (Fig. 11) is an example from this module of DP1 (Collecting Data). The students perform an experiment putting balloons into liquid nitrogen to see what happens. The student collect the data by recording what happens.

What happens if a balloon containing carbon dioxide is placed in a liquid nitrogen that is rapidly cooled?

[Preparation] carbon dioxide (exhalation), balloons, liquid nitrogen
(※ Inform students of the danger of liquid nitrogen and wear special gloves when touching it.)

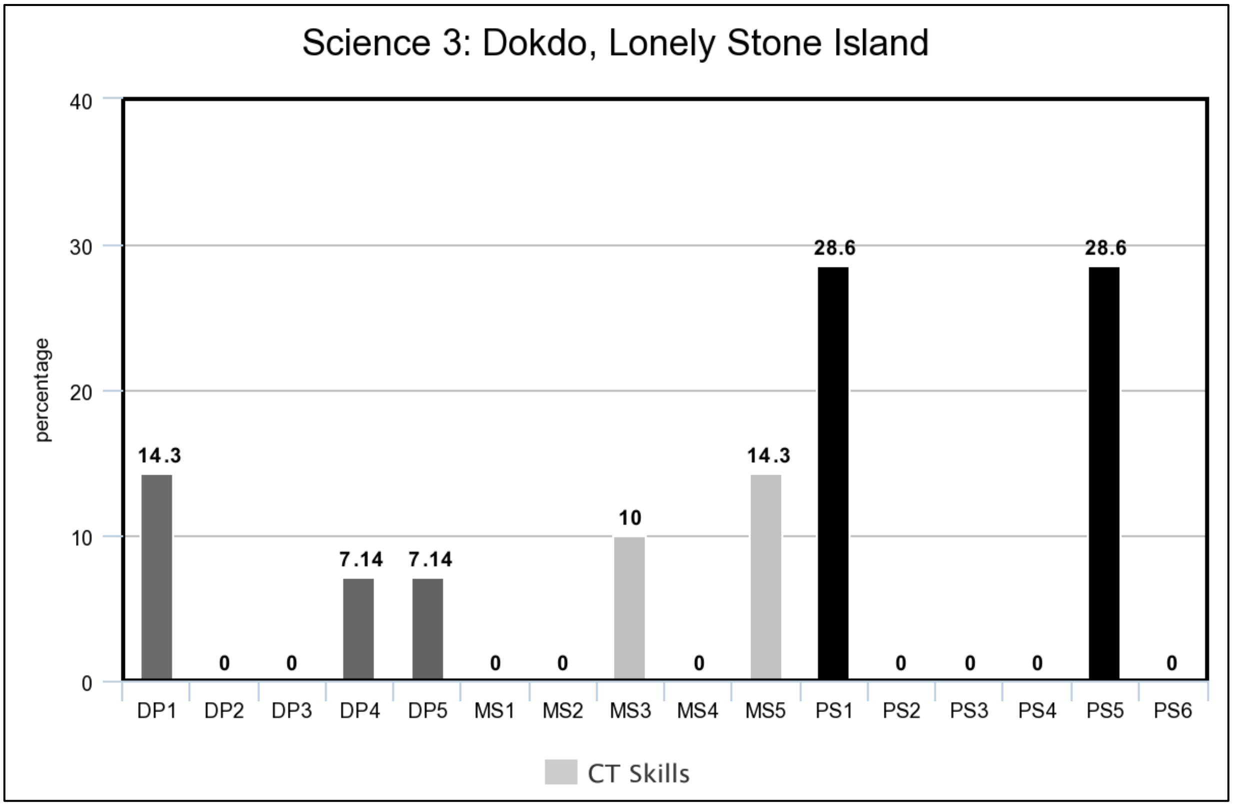


Source : zum encyclopedia

Write down what happens.

Figure 11. An example of DP1 from the 2nd Science STEAM program

The pattern of CT practices in science 3 STEAM program is displayed, whose title is '*Dokdo, lonely stone island'* (Fig. 12).



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 12. The CT pattern of the 3rd Science STEAM program and its description

There were a total of 14 practices found in this module, 4 (28.6%) Data Practices, 2 (14.3%) Modeling and Simulation Practices, and 8 (57.1%) Computational Problem Solving Practices. This module was dominated by Computational Problem Solving Practices, and almost no Modeling and Simulation Practices.

The joint most commonly found skills were PS1 (Preparing Problems for Computational Solutions) and PS5 (Creating Computational Abstractions) with 28.6% or 4 / 14 practices found in the module. 3 of the PS1 and 2 of the PS5 practices were in lesson 1 and the others were in lesson 3. None were found in lesson 2 as this is a very short lesson. There 9 examples of practices that recorded no instances. It is notable that were was no MS4 (Designing Computational Models) found in the module. In other modules the MS4 and MS5 (Creating Computational Models) were generally found together. This result shows that the two practices do not necessarily true that the two must always be present together.

Below (Fig. 13) is an example from this module of PS1 (Preparing Problems for Computational Solutions). The students decide what factors are important for Dokdo's economic value to Korea.

Supplementary Waters of Korea

'YoungHae' is called the territorial sea of 12 nautical miles (about 22km) from the coastline at the low tide when the sea water falls. In the case of an island far from the mainland, up to 12 nautical miles from the low seas of the island is defined as territorial waters.
The baseline for determining territorial waters, the "base ship" (aka low ship), is important. The base line includes a normal base line and a straight base line.
Ordinary steamers are applied to monotonous coasts or islands alone in the distant

seas. A straight line is a line that connects the outermost islands in a straight line when the coastline is complex and there are many islands near the land.

Source: Naver Encyclopedia

■ **It is clear that Dokdo belongs to the Republic of Korea in terms of its geographical location, and in terms of its territories. Think about factors that are deeply related to Dokdo's economic value and fill in the blanks.**

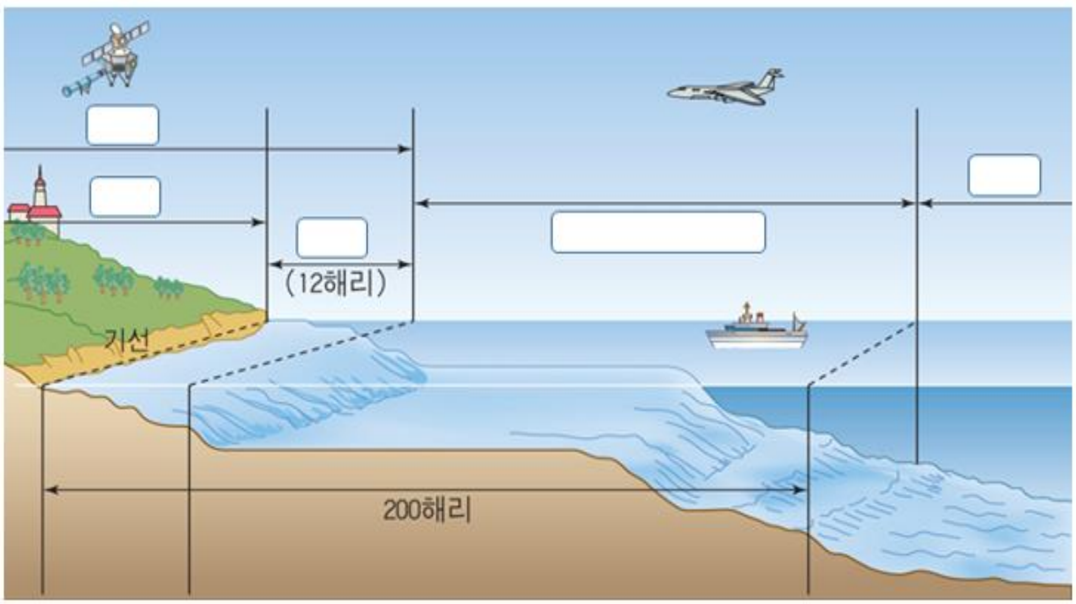
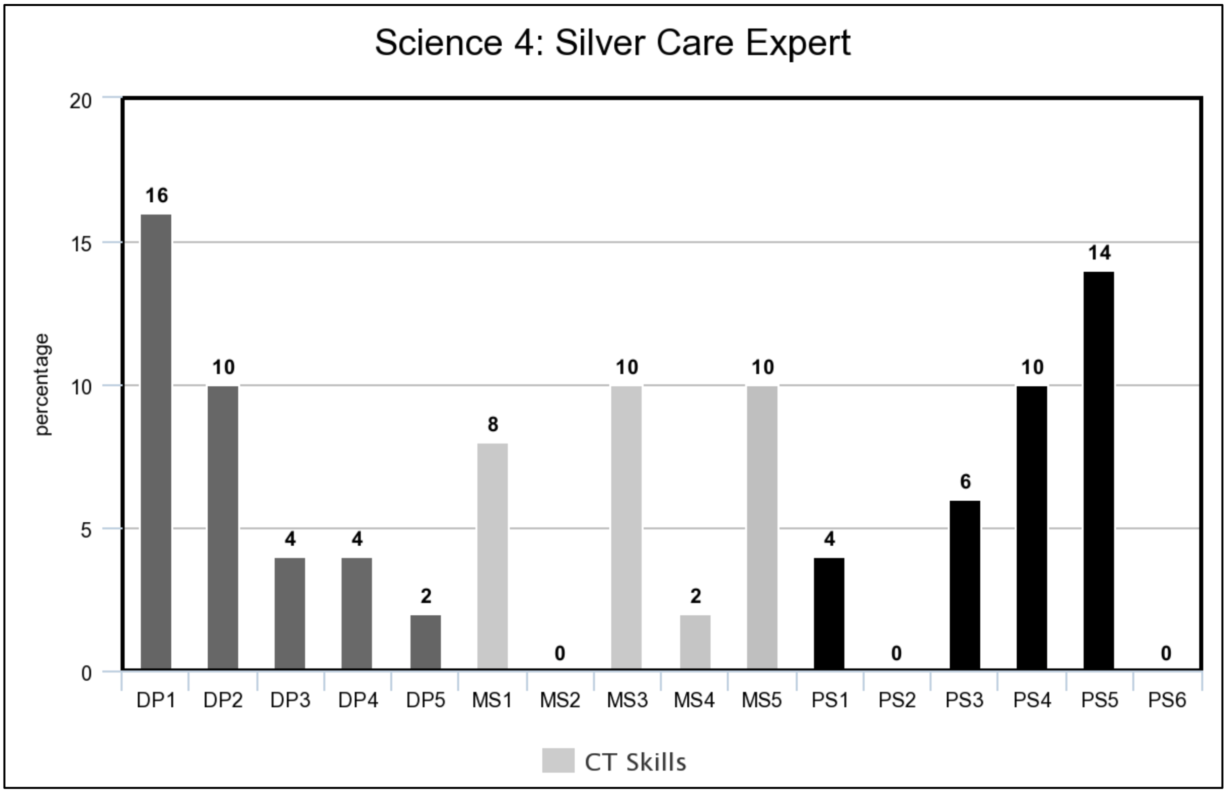


Figure 13. An example of PS1 from the 3rd Science STEAM program

The pattern of CT practices in science 4 STEAM program is displayed, whose title is '*silver care expert'* (fig. 14).



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 14**.** The CT pattern of the 4th Science STEAM program and its description

There was a total of 50 practices found in this module, 18 / 50 (36%) Data Practices, 15 / 50 (30%) Modeling and Simulation Practices, 17 / 50 (34%) Computational Problem Solving Practices. The practices are evenly distributed between the three sections

The most frequently found practice was DP1 (Collecting Data) 8 / 50 (16%). The practices were found though-out the module but mostly in lesson 1 with 5 / 8 (62.5%), 1 / 8 (12.5%) in lesson 2, and 2 / 8 (25%) in lesson 3. An example of the DP1 practice found in this module was the activity where the students have to read two extracts and find the symptoms of aging. The second most common practice was PS5 (Creating Computational Abstractions) 7 / 50 (14%). 4 / 7 (57.1%) were found in lesson 1 and 3 / 7 (42.9%) were found in lesson 3. There were no PS5 practices found in lesson 2. An example of PS5 found in this module was the activity where the students have to create a questionnaire to ask elderly people about their problems and issues. The students have to consider what questions they want to include in the questionnaire. They need to what would be the important information to ask. A total of 3 practices were found with 0 instances, MS2 (Using Computational Models to Find and Test Solutions), PS2 (Programming) and PS6 (Troubleshooting and Debugging).

Below (Fig. 15) is an example from this module of DP1 (Collecting Data). The students read information from two sources about the definition of aging. The students are collecting data from those two sources.

Think about the meaning of aging.

The following is the scientific definition of aging. After reading, find out what the symptoms of aging are.

Especially the changes that occur as we age. In 80-year-olds, high-frequency hearing is reduced by 30% at best in life, at stable levels of blood from the heart at 45%, and lung capacity at 50-60%. 70%, neurotransmission rate is maintained at 85%. Aging also reduces the mass of several body organs: 80% of liver weight is reduced by 80% and lung weight is reduced by 5%, but the brain loses only 7% on average.

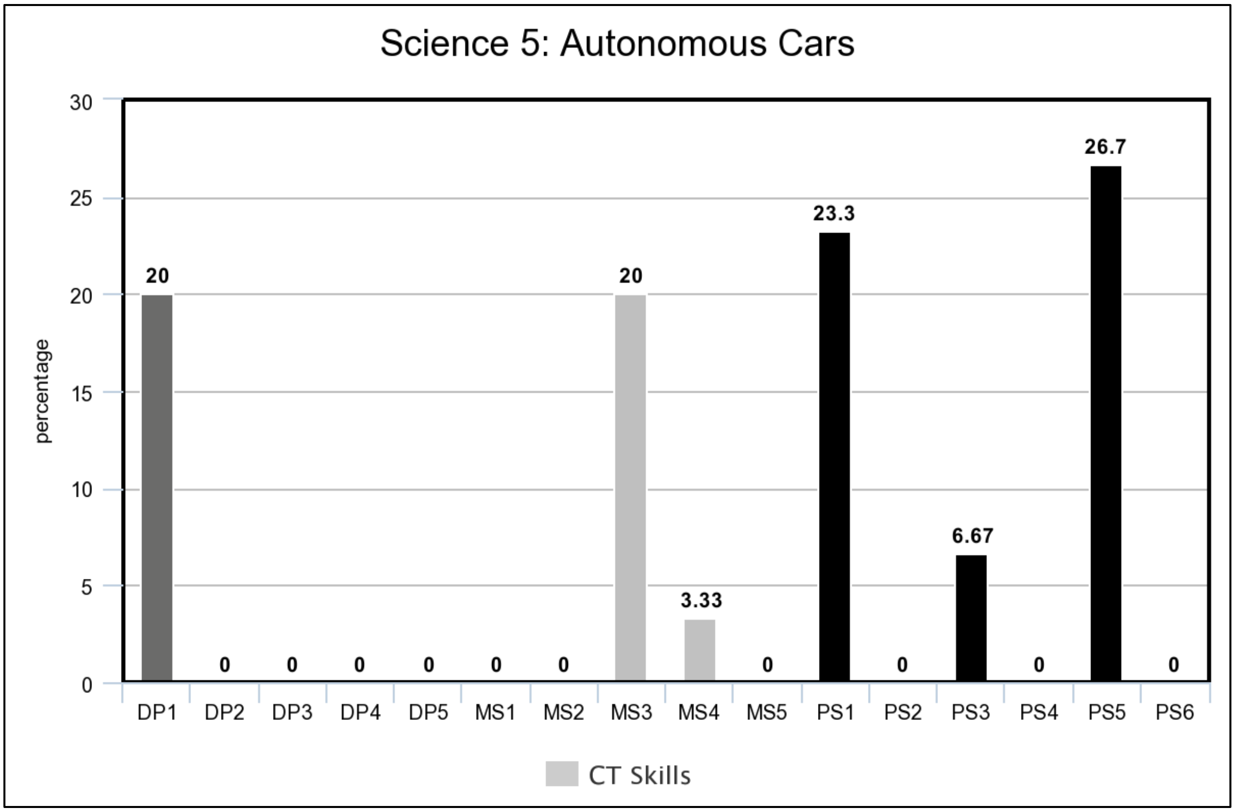
[Source] Next Encyclopedia

Aging is a disease that can be prevented. Aging can be prevented or slowed down by improved diet and lifestyle, nutrient supply, and hormone supplementation. Aging begins at the cell. The human body consists of about three trillion cells. Cells gather to form organs and organs of the body to perform various functions. However, as the aging process of cells progresses with age, the function of each organ decreases, resulting in the development of chronic degenerative diseases such as hypertension, diabetes, osteoporosis, arthritis, heart disease, and cancer. Lose and weaken.

[source] https://www.mizmedi.com

Figure 15. An example of DP1 from the 4th Science STEAM program

The pattern of CT practices in science 5 STEAM program is displayed, whose title is '*autonomous cars'* (Fig 16).



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 16**.** The CT pattern of the 5th Science STEAM program and its description

There were a total of 30 practices found in this module, 6 (20%) Data Practices, 7 (23.3%) Modeling and Simulation Practices, and 17 (56.7%) Computational Problem Solving Practices. This module was dominated by Computational Problem Solving Practices, with a similar amount of Data Practices and Modeling and Simulation Practices.

The module is led by four practices, PS5 (Creating Computational Abstractions) PS1 (Preparing Problems for Computational Solutions) DP1 (Collecting Data) and MS3 (Assessing Computational Models). There were 8 / 30 (26.7%) PS5 practices, 7 / 30 (23.3%) PS1 practices, and 6 / 30 (20%) instances of DP1 and MS3. An interesting example from this module is the cases of MS3 found. All 6 MS3 practices found were questions of an ethical or moral nature. The students had to decide what action the autonomous car should make in a given situation, e.g. should the car hit an elderly or young person? There are 10 examples of practices that recorded no instances. It is notable that although there were 6 instances of data being collected there were no activities to have the students manipulate, analyze, or visual the data.

Below (Fig. 17) is an example from this module of PS5 (Creating Computational Abstractions). In the final part "Imagination Note" of the example below the students are asked to identify what aspects of autonomous cars, socially disadvantaged and marginalized people would need help with.

Present situation

To drive a regular car, you must be eligible for a driver's license. It is a system that allows driving a car by comprehensively judging basic knowledge, skills, and functions necessary for driving a car. In Korea, there are restrictions such as age and disability to qualify for a car driver's license. It is not possible to acquire it at too young age, even if you have a hearing or hearing impairment.

For older people whose physical function is greatly reduced by aging, driving is difficult because they need to judge various situations on the road and cope quickly with sudden situations.

How convenient would it be to provide a vehicle that travels to its destination in order to provide convenience for the socially disadvantaged, such as disabled people, infants and the elderly? This is why it is important to develop science and technology that creates an environment where everyone can live like a human being, not science and technology for a specific class.

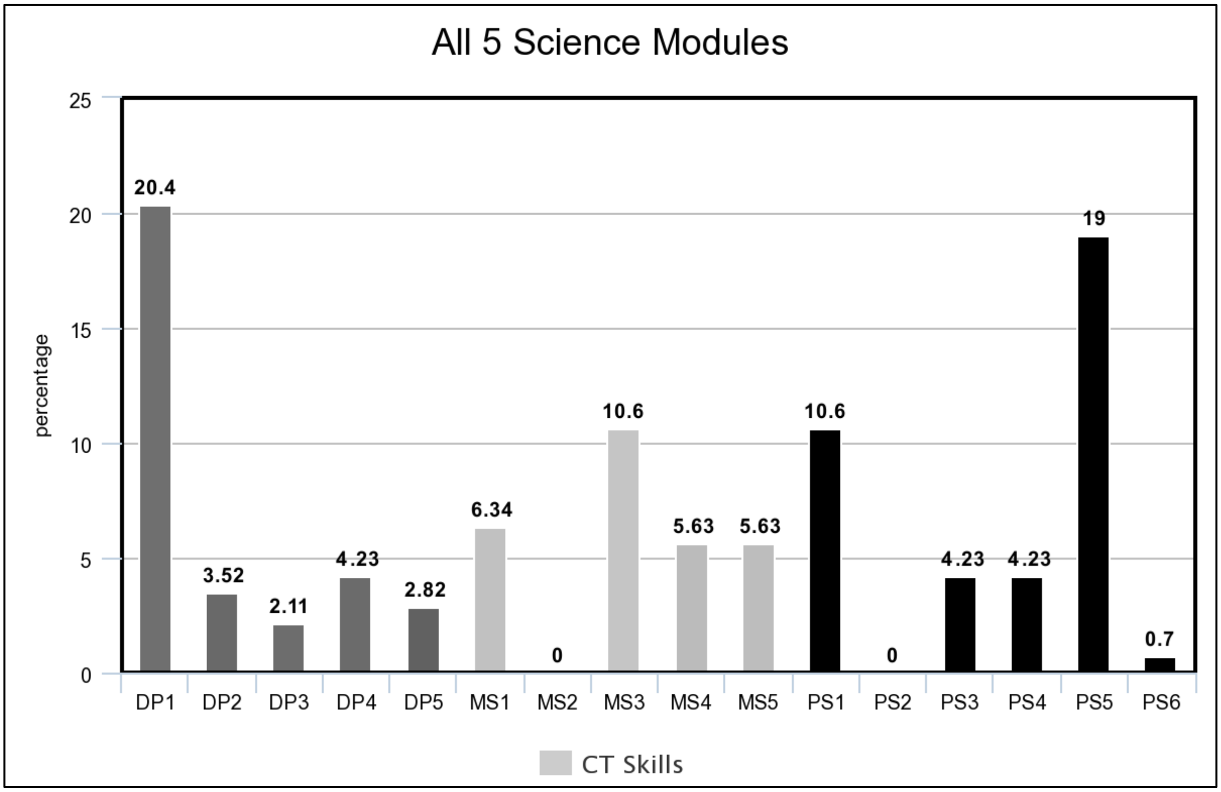
In addition to the socially underprivileged, what areas are good for incorporating autonomous driving technology? Let me give you an example.

Imagination Note

What else can you do with the technology applied to autonomous vehicles?
Or how can the socially disadvantaged and marginalized need help with autonomous driving?

Figure 17. An example of PS5 from the 5th Science STEAM program

Fig. 18 shows all 5 science modules combined together.



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 18**.** The pattern of CT uses in Science Focus STEAM programs

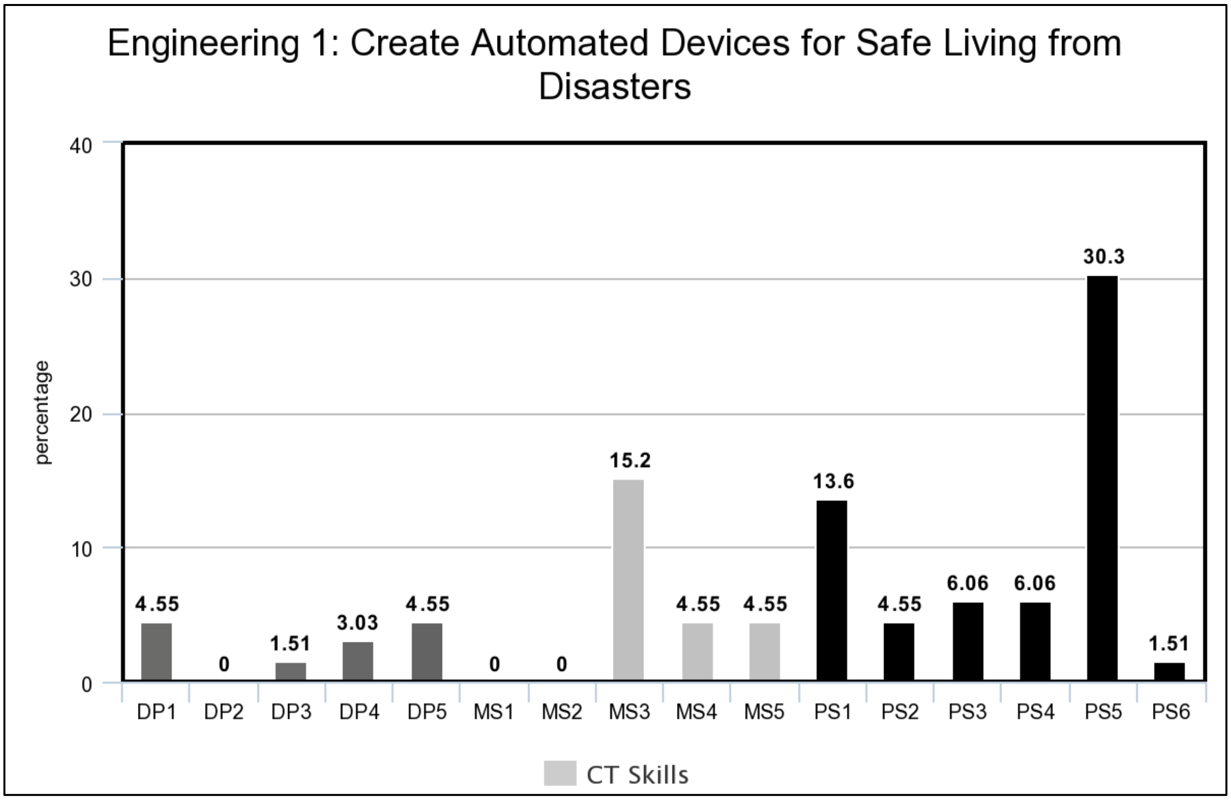
There were a total of 142 practices found in the 5 science modules combined together, 47 (33.1%) Data Practices, 40 (28.2%) Modeling and Simulation Practices, and 55 (38.7%) Computational Problem Solving Practices. Although there is a significant numbers of practices from all 3 groups there were greater numbers of Computational Problem Solving Practices found. The results also show that the Data Practices were dominated by DP1 with 29 / 47 (61.7) and Computational Problem Solving Practices were dominated by PS5 27 / 55 (49.1%) and PS1 15 / 55 (27.3%). The Modeling and Simulation Practices group, however, had a more even spread amongst the five practices.

The most commonly found skill was DP1 (Collecting Data) with 29 / 142 or 20.4% of the found practices. Of these, 19 / 29 (65.5%) were in the first lessons of the various modules. This matches the authors expectations as in our experience a popular introduction to topics / issues is to present the students with established information and asking them to find the required data points. The second most common was PS5 (Creating Computational Abstractions) with 27 / 142 (19%). 16 / 27 (59.3%) of these were found in the first lesson of the five modules. As discussed when reviewing the results from Science 1: We Will Tell You the Weather of the Universe, this is due to the possibility that PS5 is a common first step in getting students to begin to contemplate the issue at hand.

There were two practices that registered 0 occurrences, MS2 (Using Computational Models to Find and Test Solutions) and PS2 (Programming). Having no instances of MS2 is the most surprising to the authors but no PS2 is less surprising. PS2 is called programming but it is the opinion of the authors that this also includes algorithms. Actual computer programming maybe considered by some as too difficult for middle school students but it is possible and thinking in algorithms is certainly possible.

4.1.1.2 Engineering-focused STEAM modules

The pattern of CT practices in engineering 1 STEAM module is displayed, whose title is '*create automated devices for safe living from disasters'* (Fig. 19).



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 19. The CT pattern of the 1st Engineering STEAM program and its description

A total of 66 CT practices were found in this modules, 9 / 66 (13.6%) Data Practices, 16 / 66 (24.2%) Modeling and Simulation Practices, and 41 / 66 (62.1%) Computational Problem Solving Practices. These results show that this module predominately consisted of Computational Problem Solving Practices, with very few Data Practices.

The most frequently found practice was PS5 20 / 66 or 30.3%. There were spread evenly between the four lessons, 6 / 20 (30%) in the first lesson, 5 / 20 (25%) in both lessons 2 and 3, and 4 / 20 (20%) in lesson 4. An example of PS5 found in the third lesson of this module is when the students are asked to make a presentation about comparing sensors and actuators to our bodies. While the making of a presentation isn't PS5, considering what similarities and differences to include in the presentation is abstraction. The second most common practice was MS3 10 / 66 or

15.2%. 7 / 10 (70%) of those were found in the final lesson. The final lesson is about exhibition hall and showing your work to classmates. There is an example of MS3 here in that the students are asked to review the pros and cons of their classmates' automation device. There are 3 practices that were not found in this module, DP2 (Creating Data), MS1 (Using Computational Models to Understand a Concept), and MS2 (Using Computational Models to Find and Test Solutions). The fact that there was no MS1 and MS2 shows the students did no using of models to try and understand a concept or test their understanding of a concept.

Below (Fig. 20) is an example from this module of PS5 (Creating Computational Abstractions). The students have to consider what can be done to lessen the economic and societal impact of both natural and man-made disasters. They need to simplify the disasters to think about what can be done about the different types of disaster.

Natural Disasters



Meteorological Disaster | Geological Disaster | Disease Spread

Man-Made disasters

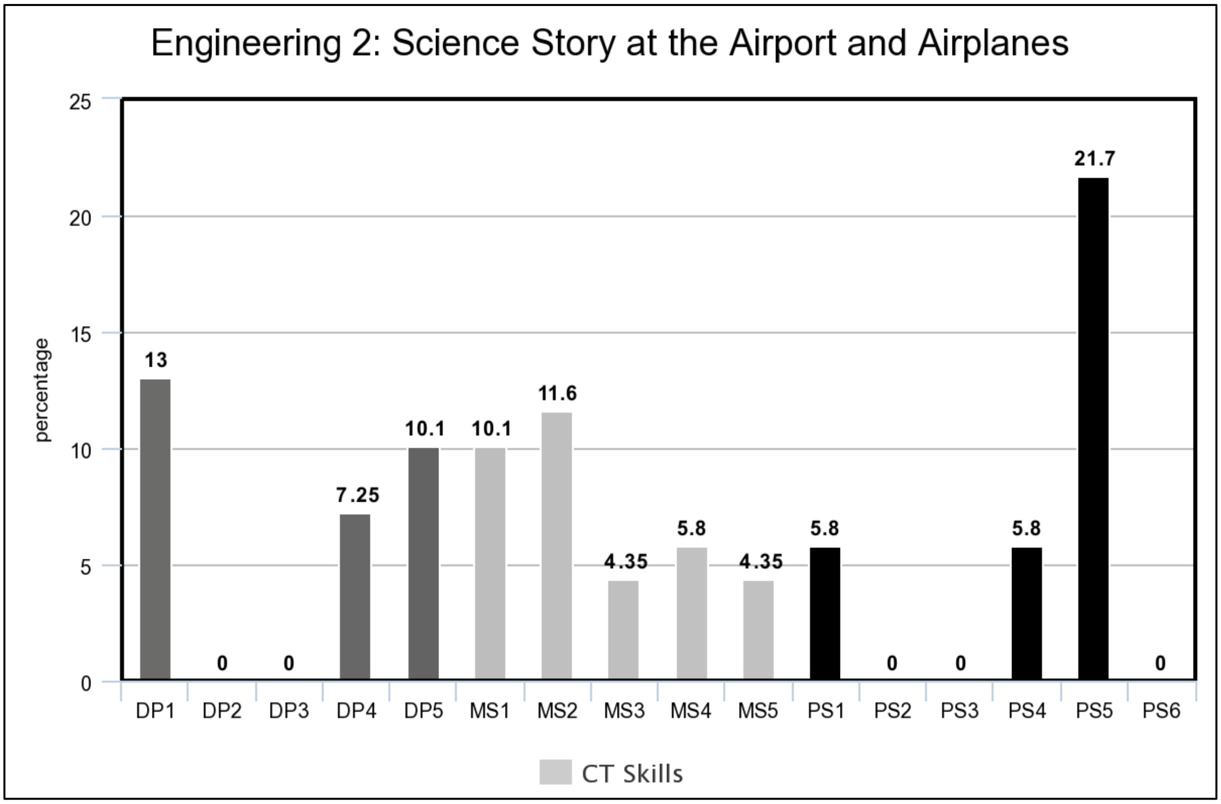


Fire | Chemical Spill | Automobile Accident

These natural disasters and man-made disasters can cause not only huge economic damage but also human damage, which is bad for us, and large-scale natural disasters and man-made disasters can cause social problems. What can we do to reduce the impact of such disasters and disasters?

Figure 20. An example of PS5 from the 1st Engineering STEAM program

The pattern of CT practices in engineering 2 STEAM program is displayed, whose title is '*science story at the airport and airplanes*' (Fig. 21).



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

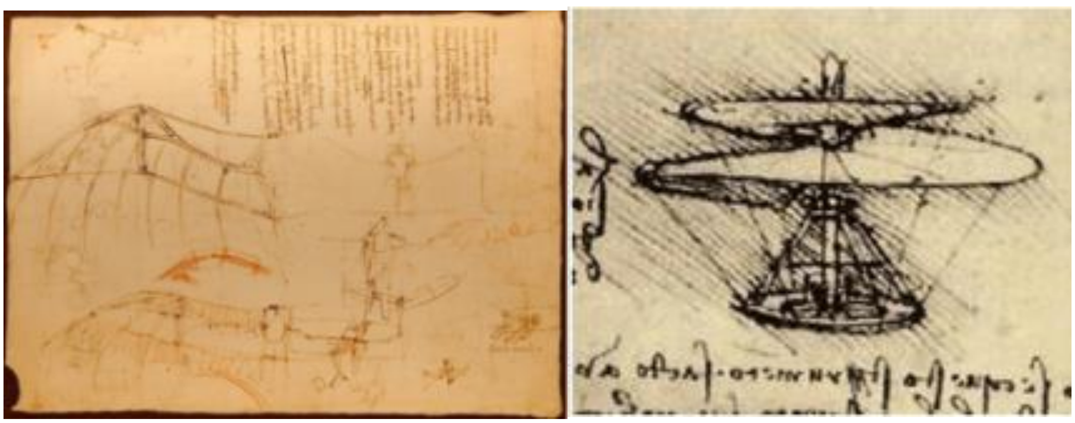
Figure 21. The CT pattern of the 2nd Engineering STEAM program and its description

There were a total of 69 CT practices found in this module, 21 / 69 (30.4%) Data Practices, 25 / 69 (36.2%) Modeling and Simulation Practices, and 23 / 69 (33.3%) Computational Problem Solving Practices. The practices were evenly distributed between the 3 groups.

The practices found the greatest number of times was PS5 (Creating Computational Abstractions) with 15 / 69 or 21.7%. Instances were found in all three of the lessons, but they were mainly found in lesson 1 and 2. There were 8 / 15 or 53.3% in lesson 1 and 5 / 15 (33.3%) in lesson 2. However, there were only 2 / 15 (13.3%) in lesson 3. The second most common practice found was DP1 (Collecting Data) with 9 / 69 (13%). They were evenly distributed between the three lessons with 3 / 9 (33%) in lesson 1, 4 / 9 (44.4%) in lesson 2, and 2 / 9 (22.2%) in lesson 3. Five of the practice recorded zero instances. They were DP2 (Creating Data), DP3 (Manipulating Data), PS2 (Programming), PS3 (Choosing Effective Computational Tools), and PS6 (Troubleshooting and Debugging).

Below (Fig. 22) is an example from this module of PS5 (Creating Computational Abstractions). The students are considering the forces in effect on a plane that is flying. They need to decide what are the forces need to be taken into account and which can be safely ignored.

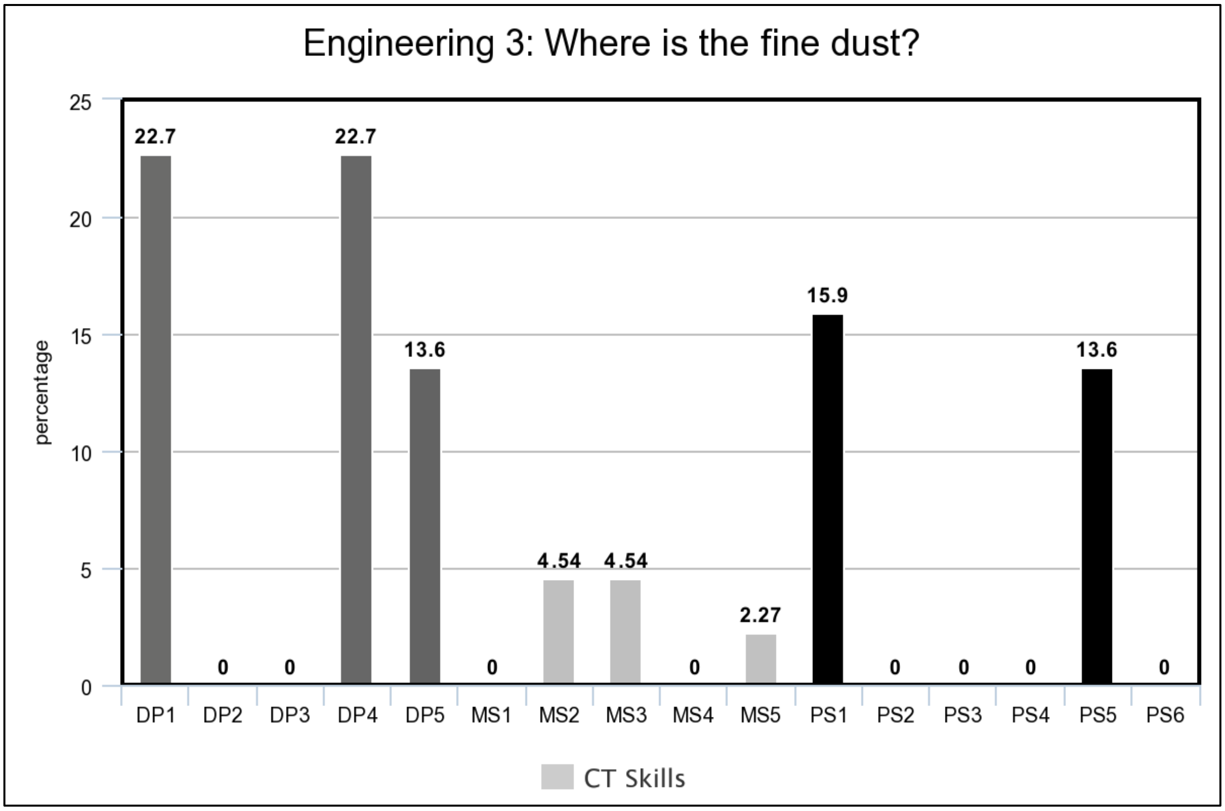
Departure



The picture is a sketch of Da Vinci. Da Vinci's sketches inspired many people and led to numerous flight experiments. After many attempts and failures, airplanes were developed, and airplanes became the usual means of transportation. How can I float an object? Discover the process of developing an idea for flying, the different forces on the plane, and the principles of flying.

Figure 22. An example of PS5 from the 2nd Engineering STEAM program

The pattern of CT practices in engineering 3 STEAM program is displayed, whose title is '*where is the find dust'* (Fig. 23).



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 23**.** The CT pattern of the 3rd Engineering STEAM program and its description

There are a total of 44 computational practices found in this module, 26 / 44 (59.1%) Data Practices, 5 / 44 (11.4%) Modeling and Simulation Practices, 13 / 44 (29.5%) Computational Problem Solving Practices. The CT practices found in this module are led by Data Practices with few instances of Modeling and Simulation Practices.

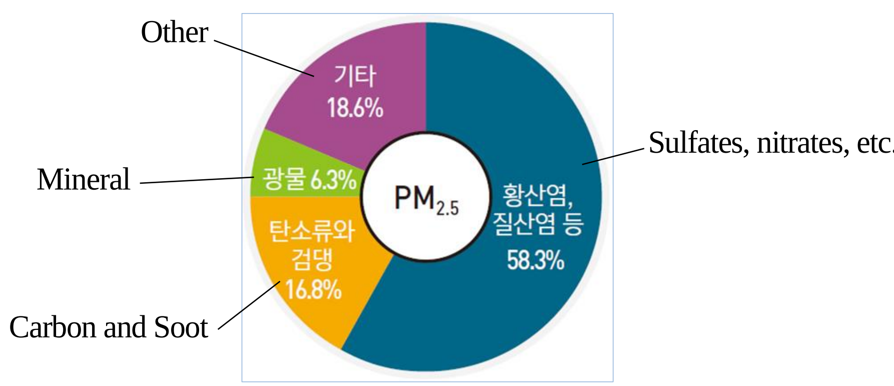
The two joint most frequently found practices were DP1 (Data Collection) and DP4 (Data Analysis) both with 10 / 44 or 22.7% of the total. 7 / 10 (70%) of DP1 and 9 / 10 (90%) of DP4 were found in the first of the two lesson of this module. For an example of DP1 found in this module is the videos that the students are asked to watch to collect information about fine dust, such as, *what is fine dust* and *how dangerous is it*? One of the DP4 practices that was found was when the students are analyzing data from the airkorea website to see if they is a difference in the fine dust concentration in the different regions of Korea. There were 8 practices that recorded 0 instances in this module. The missing modules were DP2 (Creating Data), DP3 (Manipulating Data), MS1 (Using Computational Models to Understand a Concept), MS4 (Designing Computational Models), PS2 (Programming), PS3 (Choosing Effective Computational Tools), PS4 (Assessing Different Approaches / Solutions to Problem), and PS6 (Troubleshooting and Debugging).

Below (Fig. 24) is an example from this module of DP4 (Analyzing Data). The students are presented with some information, a pie chart and an infographic. The students have to analyze the information to find the answers to the questions posed.

Fine dust, what is it?

☑ What are the fine dusts?

The composition of the fine dust may vary depending on the region where the fine dust is generated or weather conditions. Since fine dust is mainly generated during burning fossil fuels such as coal and petroleum, the fine dust measured in major regions of Korea is the highest in the air pollutants such as sulfate and nitrate.



Composition of fine dust components (%)

☑ How is fine dust generated?

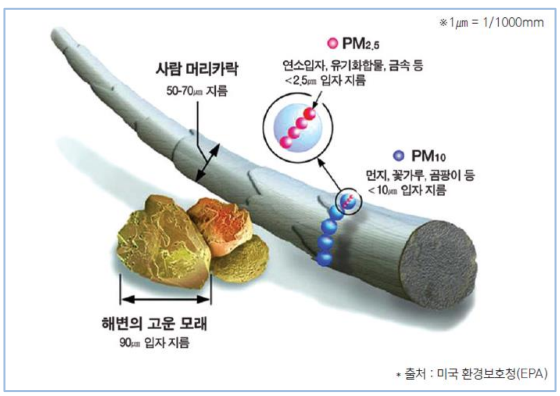
Fine dust is artificially generated, such as smoke from fossil fuel combustion, exhaust gas from automobiles, flying dust at construction sites, and incineration of materials, by-products, and incineration of garbage generated in industrial fields. .

The fine dust generator can be classified into a primary generator and a secondary generator. The discharge of solid dust from the chimney of a factory is called primary occurrence. Secondary generation is when a substance that is released as a gas is formed by chemical reaction with other substances in the air. In the case of the city, the fine dust generated secondarily by chemical reaction accounts for about two thirds.

When sulfur oxides emitted during the combustion of fossil fuels are combined with water vapor or ammonia in the atmosphere, or when nitrogen oxides of automobile exhaust gases are combined with water vapor, ozone, and ammonia, fine particles such as ammonium sulfate or ammonium nitrate are secondary. Will be created.

☑ How small is the fine dust?

Among the various sizes of dust, dust with a very small particle size is called 'fine dust'. Since fine dust is called Particulate Matter in English, it is also abbreviated as PM. Among the fine dusts, dust with a very small particle size is called 'ultrafine dust'. The standard for classifying fine dust in our daily life is the particle diameter, which is divided into fine dust (PM10) with a diameter smaller than 10 µm and ultra-fine dust (PM2.5) with a diameter smaller than 2.5 µm (1 µm = 1/1000 mm). Considering that the diameter of a human hair is 50 to 70 µm, PM10 is only about 1/5 to 1/7 of the hair, and PM2.5 is only about 1/20 to 1/30.



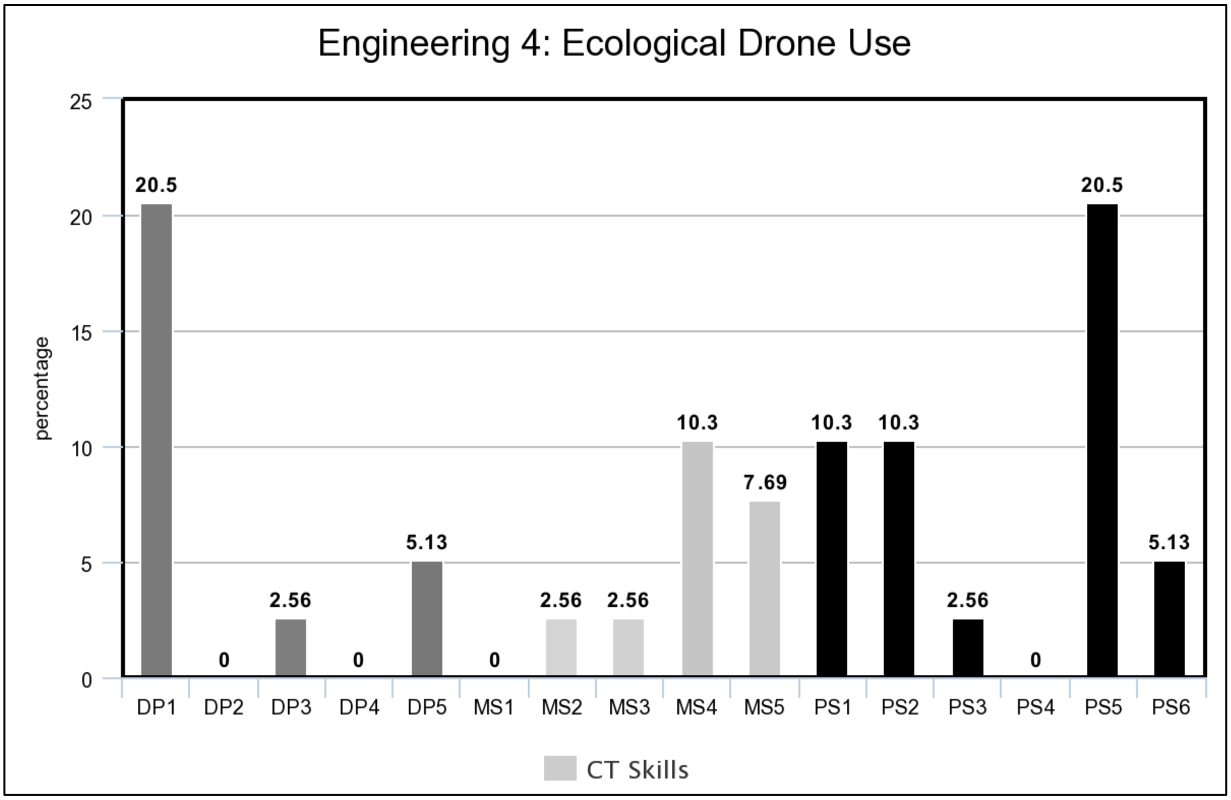
Fine dust size comparison

The Korea Environment Corporation has established the National Air Pollution Information Management System (NAMIS), which collects and manages air pollution data such as sulfur dioxide, carbon monoxide, nitrogen dioxide, ozone, and fine dust measured in the national air pollution monitoring network. Air Korea (www.airkorea.or.kr) uses this system to measure air quality standards measured in 317 city air monitoring networks, road air quality monitoring networks, national background monitoring networks and suburban air monitoring networks installed in 97 cities and counties nationwide. Provide real-time measurement data for materials. If you visit 'Air Korea', you can check the air pollution status in real time, including PM10 and PM2.5, anytime and anywhere.

(Source: Ministry of Environment, 2016, You Can See it Right Away. Fine Dust, What is It?)

Figure 24. An example of DP4 from the 3rd Engineering STEAM program

The pattern of CT practices in engineering 4 STEAM program is displayed, whose title is '*ecological drone use'* (Fig. 25).



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 25. The CT pattern of the 4th Engineering STEAM program and its description

This module contained a total of 39 CT practices found in this module, 11 / 39 (28.2%) Data Practices, 9 / 39 (23.1%) Modeling and Simulation Practices, 19 / 39 (48.7%) Computational Problem Solving Practices. Almost half of the practices found in this module were Computational Problem Solving Practices with the other half being fairly evenly split between Data Practices and Modeling and Simulation Practices.

The joint most common practice in this module was PS5 (Creating Computational Abstraction) with 8 / 39 or 20.5%. The practices were mostly found in lesson 1, with 7/8 PS5 practices found in that lesson. An example of PS5 found in this module was when the students are asked to think about what uses drones could be used for to help restore ecosystems. The other joint most found practice was DP1 (Data Collection) with 8 / 39 or 20.5%. The first activity the students were asked to perform was to watch a video to find out which plants are endangered and also about how environmental pollution can affect peoples' lives. There were 4 practices in this module that were not found, DP2 (Creating Data), DP4 (Analyzing Data), MS1 (Using Computational Models to Understand a Concept), and PS4 (Assessing Different Approaches / Solutions to a Problem).

Below (Fig. 26) is an example from this module of DP1 (Collecting Data). The students have to collect data about their classroom in order to able to program their drone's flight path.

6-3 Autonomous Drone Programming Practice

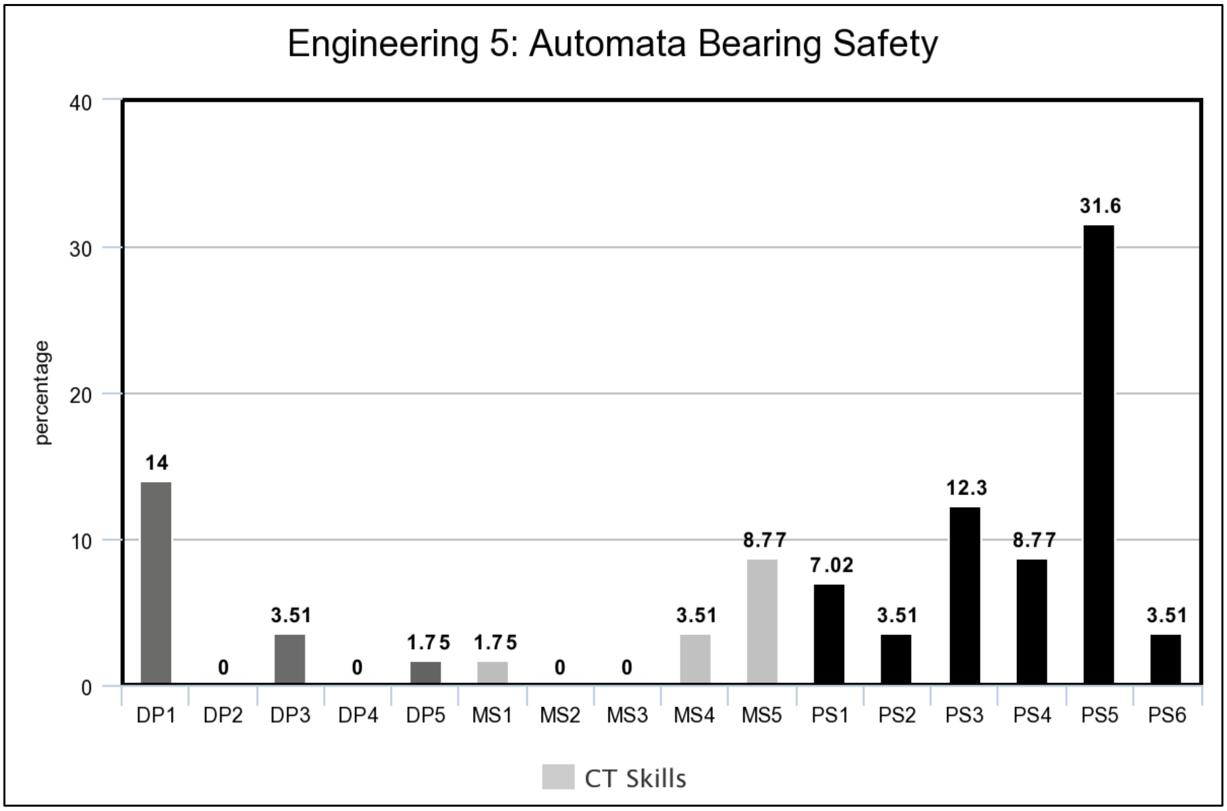
Let's select a virtual object in the classroom and program the drone to get there.

Let's collect data that can program the flight path to the object selected by the drone.
(※ You need to control variables such as external force)

For programming collecting data	◈ Flight distance : ◈ Flight time: ◈ Flight height: ◈ Battery consumption : ◈ Weight of flying aircraft :

Figure 26. An example of DP1 from the 4th Engineering STEAM program

The pattern of CT practices in engineering 5 STEAM program is displayed, whose title is '*automata bearing safety'* (Fig. 27).



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 27**.** The CT pattern of the 5th Engineering STEAM program and its description

A total of 57 CT were found in this module. There were 11 (19.3%) Data Practices, 8 (14.0%) Modeling and Simulation Practices, and 38 (66.7%) Computational Problem Solving Practices. This module was dominated by Computational Problem Solving Practices.

The most commonly found skill was PS5 (Creating Computational Abstractions) with 31.6% or 18 / 57 skills found in the module. The 18 practices were found through-out the three modules, but half (9 / 18 50%) were found in lesson 1. An example of the PS5 found in this module was when the students were asked to consider what safety problems there are in their school and how they can be solved. The second most found were DP1 (collecting data) with 14% or 8 / 57. An instance of DP1 found in this module is the activity the students did where they watched a video to learn the name of the different types of gears. There 4 examples of skills that recorded no instances. With there being 8 instances of DP1 then DP4 (Analyzing Data) is normally found as the students analyze the data.

Below (Fig. 28) is an example from this module of PS5 (Creating Computational Abstractions). The students looking at seven different safety areas considering what are the important safety incidents that should be acknowledged in the different areas.

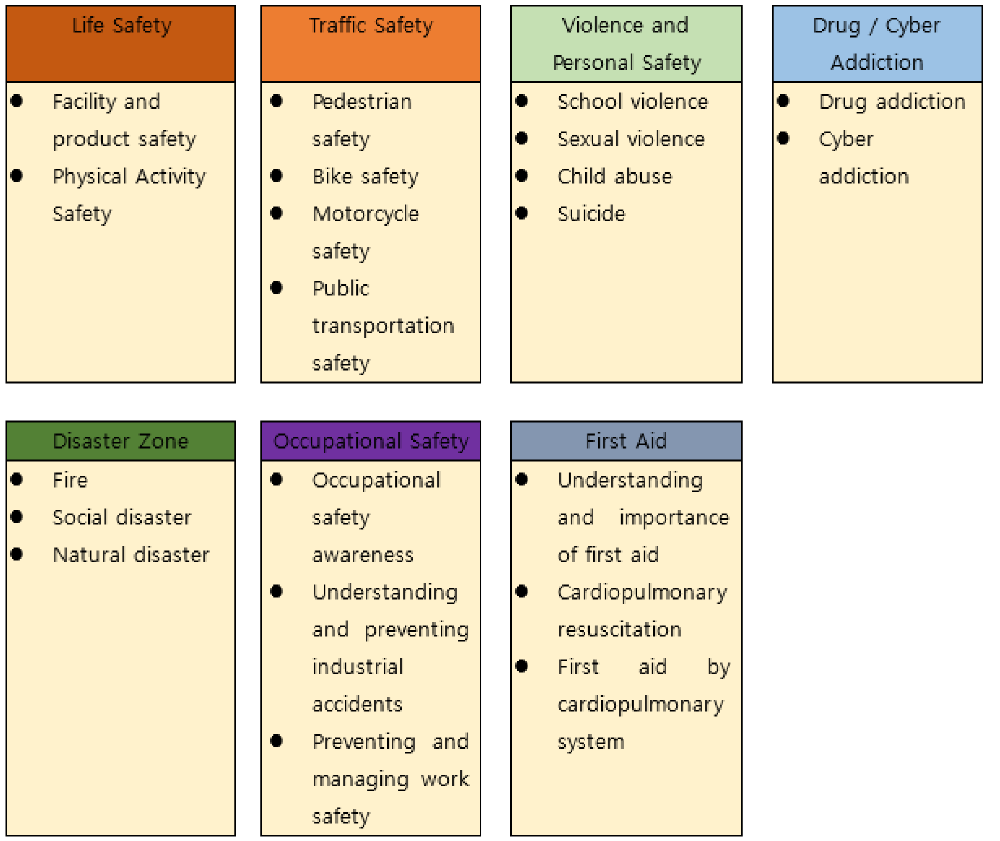
Thinking

Raising thoughts

5. The following are seven safety areas. Look at the details of each area and think about what are the examples of safety incidents around us.

Seven safety zones ...

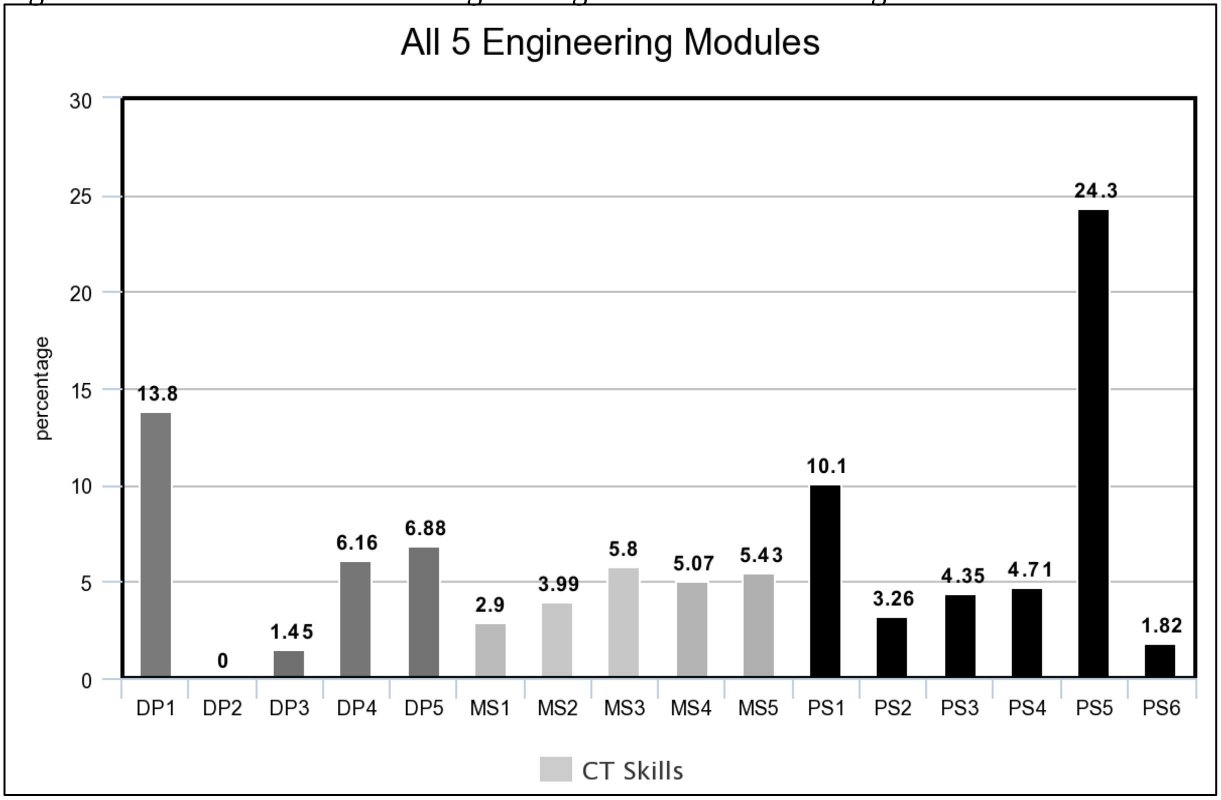
1. Life safety to prevent safety accidents that may occur in everyday life (including facility safety, indoor and outdoor activities, physical activities, leisure activities, and dietary safety)
2. Traffic safety (including pedestrians, bicycles, motorcycles, cars, public transportation, etc.) to prevent safety accidents caused by transportation
3. Safety for the prevention of violence and for protection of the person (including school violence, sexual violence, child abuse, suicide, etc.)
4. Drug and cyber addiction safety (including smoking, alcohol, medicine, games and the Internet, smartphones, and information security)
5. Disaster safety (including fires, explosions, collapses, typhoons, floods, earthquakes, etc.) to prevent and prepare for fires and disasters
6. Occupational Safety and Safety to Prevent Safety Accidents at Work
7. First Aid Training



<Source> Busan Office of Education

Figure 28. An example of PS5 from the 5th Engineering STEAM program

Fig. 29 shows the results for all 5 engineering modules combined together.



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 29**.** The pattern of CT uses in Engineering Focus STEAM programs

There were a total of 276 practices found in the 5 engineering modules combined together, 78 (28.3%) Data Practices, 64 (23.2%) Modeling and Simulation Practices, and 134 (48.5%) Computational Problem Solving Practices. Although there is a significant numbers of practices from all 3 groups there were greater numbers of Computational Problem Solving Practices found. The results also show that the Data Practices were dominated by DP1 with 38 / 78 (48.7%) and Computational Problem Solving Practices was dominated by PS5 with 67/134 (50%). The Modeling and Simulation Practices group, however, had a more even spread amongst the five practices. The most commonly found skill was PS5 (Creating Computational Abstractions) with 67 / 276 or 24.3% of the found practices. The second most common was DP1 (Collecting Data) with 38 / 276 or 13.8%. There was one practice that registered 0 occurrences, DP2 (Creating Data).

We might speculate that DP2 is too difficult for middle school age students. It is for the times when collection of data is infeasible, i.e. galaxy formation or plate tectonics.

4.1.2 Analysis of Results 1

As can be seen from figures 8 to 29 almost all of the CT practices are exposed to some degree. The first result to note is that the three most commonly found practices in the science modules DP1 (Collecting Data), PS5 (Creating Computational Abstractions), and PS1 (Preparing Problems for Computational Solutions) were also the three most strongly exposed practices found in the engineering modules. The practices that recorded no instances in the science modules were MS2 (Using Computational Models to Find and Test Solutions) and PS2 (Programming). While the only unrepresented practice was DP2 (Creating Data) for the engineering models, all three (MS2, PS2, and DP2) were weakly exposed in both the science and engineering modules.

These results show that the discipline (science versus engineering) does not dictate which CT practices will be found in the module. During the analysis of the modules the researcher noticed that the CT practices being found was determined by the nature of the activities the module designer created for the module. If the module had many hands on activities designing and making models to test then the MS (Modelling and Simulation Practices) would more strongly exposed. If the module was more data orientated then the DP (Data Practices) would be more strongly exposed.

4.2 Results 2: Promoting CT Practices

4.2.1 Improving the missing/weakly exposed CT practices

In this section the researcher will answer the second research question of what CT practices can be suggested to revitalize weakly exposed CT practices in STEAM programs on the basis of the descriptions made is the above section. In this study, the relative weakly exposed or missing CT practices of each module (5 science and 5 engineering) was developed and introduced. We developed the possible improved CT on the basis of the analyzed pattern of CT as follows.

There are 10 different STEAM programs in this study and each module consists of a few or more lessons. A sample from each science and engineering focused STEAM module is introduced to show how more CT practices can be improved. Five sequence steps are provided to show how the improved CT can be developed; (1) introduction of the module, (2) the context of the lesson where CT practice can be improved, (3) the activity to be improved, and (4) the finalized activity where improved CT practices is added. The following sample of suggesting how CT practices could be improved from the weak to the strong exposed ones in science focus STEAM program. The first sample is from science 1 focus STEAM program, whose title is '*we will tell you the weather of the universe*' (Table 26).

Table 26. The improvement of CT practices by adding the activity in science STEAM program

Science 1: We Will Tell You the Weather of the Universe

CT practices improved in this module: MS5 + PS2 + PS6

The introduction of the module (3 lessons)

This module is composed of three lessons, "When the Sun goes Boom, the Earth is Bruised", "Space Weather Forecast and Special Report Through Observation of Solar Activity", and "Creating a Space Environment Forecast Application". This suggested additional activity is to be added to the second lesson.

The context of the 1st lesson

The first lesson starts with the students investigating the damage that can be caused by solar flares. They then look at the solar activity over the last 100 years and see how common instances of increased sunspots are. Next, and final activity of lesson 1, is to look at the phenomenon caused by solar activity and the effects they can have.

The context of the 2nd lesson

Lesson 2 starts with a look at how space weather can effect live on Earth, such as GPS, wireless communication, and flight. The activity that is it is suggested to add to is next. The original activity (screen capture shown below) involves the students looking at the Space Weather Center and Space Weather Forecast service site to see the information the website gives about space weather elements and what forecast they provide.

Original Activity in the lesson

★ Space weather forecase system

Let's explore space weather center and space weather forecast service site and arrange solar observation information and meteorologicla factors

Information/weather elements	Contents	Application Plan

How to improve CT practice

The suggested activity would be done by the students after the activity shown above. The purpose of the suggested activity is <u>to give the students the chance to experience</u>

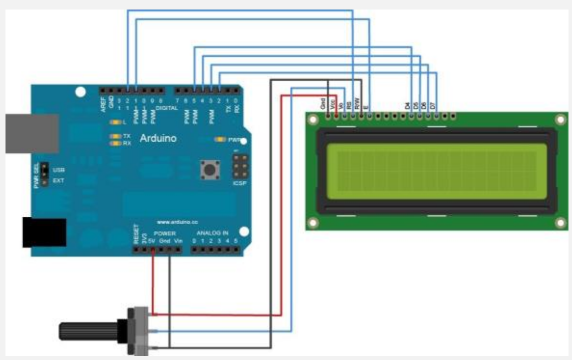
programming. As shown by Clements & Gullo (1984), programming provides a situation for students to practice effective thinking processes. As was argued by Margolis et al (2008) programming is often seen as something that can only be done by the "best and the brightest". This activity can therefore be used to introduce programming to every student regardless of ability, gender, or ethnicity and show them that it can be done by anyone. The following activity is suggested to improve a few CT practice. The programming language used is Python, which along with other languages like Scratch is easier for students to learn due to the lesser amount of programming syntax (Lye & Koh, 2014). The easy programming languages are useful as it allows students to concentrate on the CT practices rather than stressing about writing the programming (Kelleher & Pausch, 2005).

Suggested Activity in the lesson

Let's make an early warning system for space weather.

We will construct and program an Arduino to check the space weather website and provide a live RSS feed of space weather information.

1. Set-up the Arduino as follows: ***(MS5 skill added)***



2. Download the easy to learn programming language Python (www.python.org).
3. 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". ***(PS2 skill added)***
4. If your RSS feed doesn't work, check these 3 things to find the mistake***. (PS6 skill added)***
   a) Check the port in the python file. Your Arduino may be labeled differently or be numbered differently.
   b) Check that the RSS feed doesn't have a ~ in the data.
   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.

(Arduino set-up and programming taken from https://www.instructables.com/id/Wiring-up-the-LCD-and-the-LED/)

The above science focus STEAM program has the pattern of highly used CT practices in DP1, DP4, MS3, MS4, and PS5. More CT practices of MS5(missing), PS2(missing), and PS6(weakly exposed) were developed and added and this improved STEAM program could give students chances to experience more extended CT practices as envisioned ones. The following sample is from science 2 focus STEAM program, whose title is '*burning ice, gas hydrate*' (Table 27).

Table 27. The improvement of CT practices by adding the activity in science STEAM program

Science 2: Burning Ice, Gas Hydrate
CT practices improved in this module: MS2 + DP4 + DP5
The introduction of the module (2 lessons) *This module is split into two lessons, "Burning Ice, Gas Hydrate" and "How to Transport Gas Hydrate Safely?". This suggested change is done to the first lesson.* **The context of the 1st lesson** *The start of the lesson is the students learning about gas hydrate. The lesson starts with the students learning about the importance of gas hydrate to Korea due to the large quantity under the sea bed near Dok-do Island. The students then learn that gas hydrate is methane gas under high pressure and low temperatures that are encased in water molecules, and its advantages and disadvantages. They also construct a molecular model of gas hydrate to help the student visulize its structure. The students learn how deposites of gas hydrate are a possible solution to the Bermuda Triangle. At the end of this lesson the students perform some experiments to learn about and compare the differences between solid, liquid, and gaseous fuels. This activity is the second to last activity done in the first lesson and for to students to observe the difference in volumes of an equal mass of solid, liquid, and gaseous fuel.* **Original Activity in the lesson** **★ Compare fuels in solid, liquid and gas** Measure the mass of your solid fuel and compare the volume of the same mass of liquid and gas in a container. (In the case of liquid and gaseous fuels, there is a risk of fire and explosion. Replace with water and carbon dioxide.)

[Preparation] Solid fuel, water (replacement of liquid fuel), carbon dioxide (replacement of gaseous fuel), balloon, scale

[Step 1] Place the solid fuel on the balance and measure the mass.
[Step 2] Fill the balloon with water as measured mass.
[Step 3] Fill the balloon with carbon dioxide (exhalation) as much as the measured mass.
[Step 4] Compare the volumes of three states of equal mass.

Write the volumes of solid fuel, water and carbon dioxide of the same mass in order and write down the reason.

How to improve CT practice

The suggested activity would be a replacement for the original activity. The suggestion is to have a nine step process (shown below) instead of the original four step process. The suggested activity is designed to introduce the MS2, DP4, and DP5 practices. The introduction of MS2 gives the chance to make sure they understand the differences and similarities between the solid, liquid, and gaseous fuels.

Suggested Activity in the lesson

[Preparation] Solid fuel, water (replacement of liquid fuel), carbon dioxide (replacement of gaseous fuel), balloon, scale

[Step 1] How do you think the respective volumes of the same mass of solid, liquid, and gaseous fuels will compare to each other? Which will have the greatest volume and which will have the smallest volume?
[Step 2] Place the solid fuel on the balance and measure the mass.
[Step 3] Fill the balloon with water as measured mass.
[Step 4] Fill the balloon with carbon dioxide (exhalation) as much as the measure mass.
[Step 5] How does the volume of the solid, liquid, and gaseous fuel compare to your prediction? ***(MS2 Skill added)***
[Step 6] What do you think would happen to the differences in volumes if the mass was increased or decreased?
[Step 7] Repeat steps 2-4 with different masses of fuel.
[Step 8] Draw graphs showing how the volume of the three fuels changes as the mass is increased and decreased. ***(DP5 skill added)***

[Step 9] Analyze the graphs to decide which type of fuel would take the least space to transport. ***<u>(DP4 skill added)</u>***

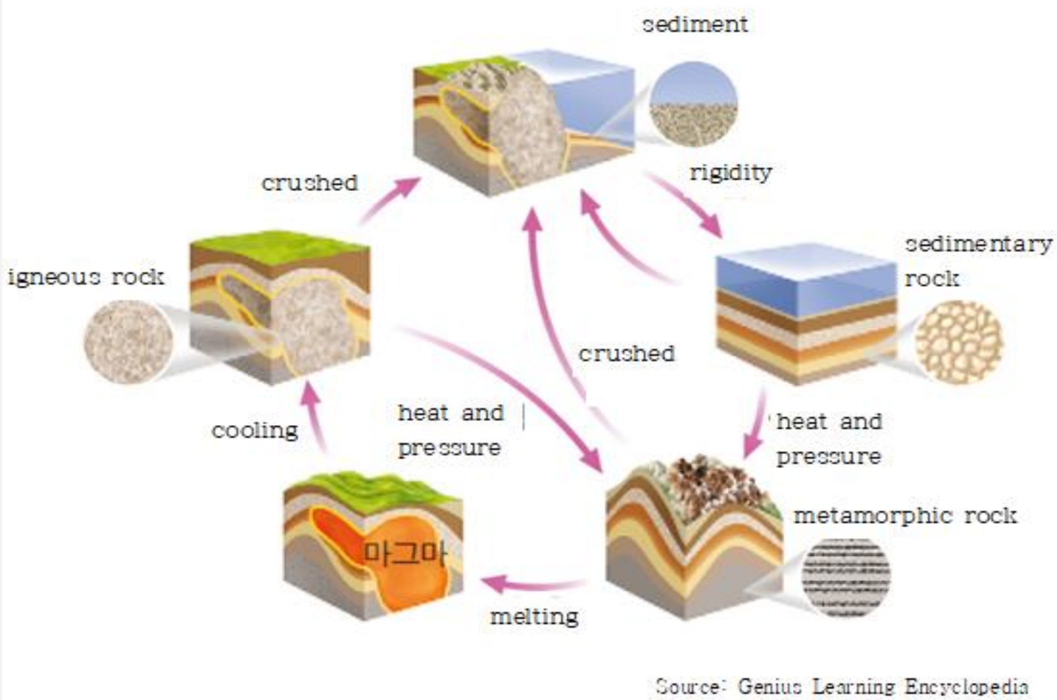
The above science focus STEAM program has the pattern of highly used CT practices in DP1 and MS1. More CT practices of MS2(missing), DP4(missing), and DP5(missing) were developed and added and this improved STEAM program could give students chances to experience more extended CT practices as envisioned ones. The next sample is from science 3 focus STEAM program, whose title is '*Dokdo, lonely stone island*' (Table 28).

Table 28. The improvement of CT practices by adding the activity in science STEAM program

Science 3: Dokdo, Lonely Stone Island
CT practices improved in this module: MS1 + MS2
The introduction of the module (3 lessons) This module consists of three lessons called "The Secret of Dokdo's Birth", "What does Dokdo Look Like?", ad "Our Reminder of Dokdo." This suggested change is part of the first lesson. **The context of the 1st lesson** *The lesson starts with the students looking at the name Dokdo's meaning and also the historical names for Dokdo. They also look at the names used by other countries for Dokdo. The second activity is to watch a video describing the birth of Dokdo as an underwater volcano and the gradually erosion of the sedimentary rocks over millions of years to leave Dokdo at its current size. The suggested change should be added to the follow up for the video the students watch.*

Original Activity in the lesson

■ Let's look at the characteristics of the rocks that make up the crust generated as a result of volcanic activity.



◪ The rocks are classified into igneous rocks, sedimentary rocks, and metamorphic rocks according to their production process. Write a rock that is suitable for the blank.

How to improve CT practice

In its original form this activity is for the students to consider the characteristics of igneous, sedimentary, and metamorphic rocks. As can be seen in the screen capture below the students are presented with a diagram showing how the different types of rock are made. It is a very good diagram but the students are not very likely to really remember the information effectively from just looking at the diagram.
This suggested activity would be inserted into the lesson after the above activity. The hands on experiment is much more likely to facilitate the learning process and result in a much greater retention of the knowledge by the students.

The activity is that the students will be provided with rock samples by the teacher. The students should look at the rocks through a hand lens. From their observations they can but the rocks into groups of similar characteristics. They can then determine which group would *be igneous, sedimentary, and metamorphic. They can then test their model of rock determination by being given another rock(s) and trying to decide if it is igneous, sedimentary, or metamorphic.*

Suggested Activity in the lesson

Your teacher will provide your group with some samples of different rocks. Investigate the characteristics of the rocks using hand lenses. Put the samples into three groups. The rocks in each group should have similar characteristics. Try to decide which group is igneous, sedimentary, and metamorphic. Check your answer with the teacher ***(MS1 skill added)***

Your teacher will provide your group with a new sample of rocks. Using the knowledge learned about igneous, sedimentary, and metamorphic rocks, split the rock samples into the three categories. ***(MS2 skill added)***

Provide some reasons why you think the rocks belong in the category your group place it. (e.g. sedimentary because there are many layers)

The above science focus STEAM program has the pattern of highly used CT practices in DP1, MS5, PS1, and PS5. More CT practices of MS1(missing), and MS2(missing) were developed and added and this improved STEAM program could give students chances to experience more extended CT practices as envisioned ones. The next sample is from science 4 focus STEAM program, whose title is '*silver care expert*' (Table 29).

Table 29. The improvement of CT practices by adding the activity in science STEAM program

Science 4: Silver Care Expert

CT practices improved in this module: MS5 + PS2 + PS6

The introduction of the module (3 lessons)

This module consists of three lessons titled, "Empathize with Grandma and Grandpa", "Grandma and Grandpa Read math", and "I am an Advanced Silver Care Professional". This suggested change is part of the third lesson.

The context of the 3rd lesson

The third lesson starts with a video to introduce the idea of 'smart healthcare' and the advantages it could involve for the elderly and people at higher risks of disease. The students then look at many examples of smart healthcare products that have been designed to help elderly people in a variety of different ways. Then as part of a group discussion the students discuss a product they would like to make that is related to silver healthcare. The students are then given the example of elderly people forgetting to take their medicine when they go out and asked to think of some solutions. This is the activity depicted below.

Original Activity in the lesson

- ❖ What solutions currently exist to address the difficulties in question 3? As you explore the Internet or observe the experiences of older people around you, share your experiences with the group and find out what solutions you are using.

number	Difficulty	Current Solution	Source
1	Do not take medicine when going out	Large post-it nite on the front door	experience
2			
3			

- ❖ What better way is there than the sugguested solution/ Analyze the shortcomings of existing solutions, or write a random post-it note in your head.

Collect all your post-it notes and sort them by device, app, or tool. If you have more ideas during the classification process, you can include them in different colored post-it notes.

How to improve CT practice

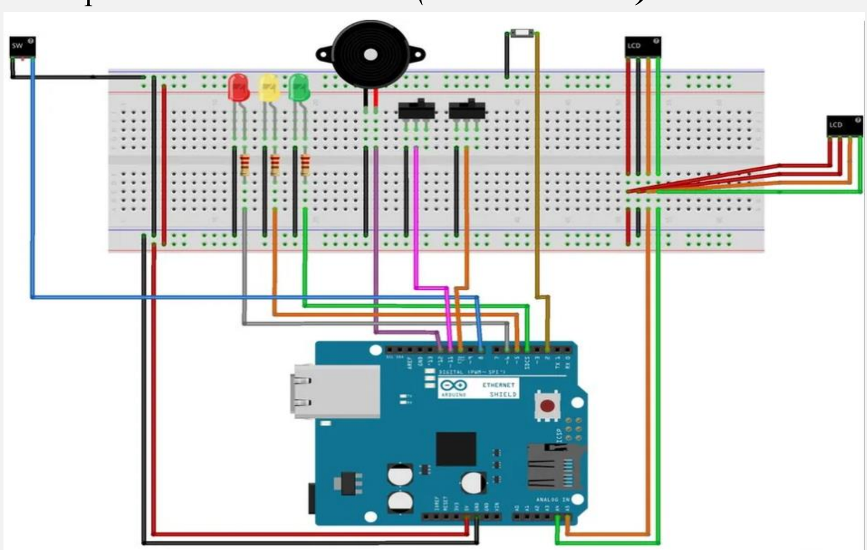
The suggest activity below would be done after the students have performed the above activity. The activity would introduce a practical element into what is a lesson dominated up until then by theoretical activities. As a programming practice it also includes all the positive aspects involved with that. This was discussed in greater detail in the suggested activity for Science 1.

Suggested Activity in the lesson

Let's make a door alarm to help Grandma and Grandpa remember to take their medicine.

We will construct and program an Arduino that sounds an alarm and/or send a message when a door is opened.

1. Set-up the Arduino as follows: ***(MS5 skill added)***



1. Mount the Reed Switch. The Reed Switch is a magnetic sensor that activates when the door is opened or closed. ***(MS5 skill added)***
2. You will need to import the Arduino code to your Arduino. The teacher will provide the code for you. (It can also be found easily by searching the internet for "ArduinoDoorAlarm.ino". ***(PS2 skill added)***
3. Next will be to set-up the alert messages. First create a free twilio.com account. Create a project and phone number and don't forget to record the account SID and Auth Token. Upload the Twilio PHP master to you web server (https://packagist.org/packages/twilio/sdk). Upload the alert.php code to the same directory (Search for "alert.php.txt"). ***(PS2 skill added)***
4. If your alarm is not working then try to troubleshoot the problem using suggestions

from https://www.arduino.cc/en/guide/troubleshooting. ***(PS6 skill added)*** (Arduino set-up and programming taken from https://www.instructables.com/id/Arduino-Door-Alarm-With-Text-Alerts

The above science focus STEAM program has the pattern of highly used CT practices in DP1, DP2, MS3, MS5, PS4, and PS5. More CT practices of MS5(well represented), PS2(missing), and PS6(missing) were developed and added and this improved STEAM program could give students chances to experience more extended CT practices as envisioned ones. The final sample of the science focused STEAM programs is from science 5, whose title is '*autonomous cars*' (Table 30).

Table 30. The improvement of CT practices by adding the activity in science STEAM program

Science 5: Autonomous Cars
CT practices improved in this module: DP3 + DP4 + DP5
The introduction of the module (3 lessons) This module consists of three lessons titled, "Autonomous Cars, It Wants to Know!", "Seen as Omnipresent 'Autonomous Driving Technology'", and "Autonomous Car, Solomon's Wisdom". This suggested activity would be implemented in the first lesson. **The context of the 1st lesson** The lesson starts with the students reading about the current situation for autonomous cars. They then watch a video about their future lives. After the video the students make a simple sketch of what their think cars of the future will look like and label some of the features. The next activity is the one depicted below in the screen capture. The students investigate the development trends of four major companies developing autonomous cars.

Original Activity in the lesson

Company	Autonomous Vehicle Development Trend
Google (Waymo)	
Mercedes / Daimler	
Naver	
Hyundai / KIA	

✹ Based on the findings, let's anticipate when autonomous cars become commonplace and explain why.

____

____

How to improve CT practice

This suggest activity would be done in addition to the above activity. It is a follow up to the activity with the students doing some manipulation, analysis and visualization of the data they researched about the companies' development trends. It is hoped that this will give the students a greater understanding of the direction that the companies are taking with autonomous cars and the issues that are important to them.

Suggested Activity in the lesson

Based on your research into the trends for the companies give the companies a score (1-5) based on how important the issue appears to be to the company. A score of 5 is very important and 1 is not important. You can judge the score based on how near the top of the website the information is presented and how much information there is. The issues to judge the companies on are:

a) safety of the cars / humans in the car.
b) safety for pedestrians
c) helping differently abled people / the elderly / children with mobility
d) economics of self-driving cars

e) military applications f) environmental concerns g) time management ***(DP3 + DP4 skills added)*** Produce a graph (pie chart) showing the combined score for the companies in the judged issues. What are the most important issues the companies are trying to solve with self-driving cars? ***(DP5 + DP4 skills added)***

The above science focus STEAM program has the pattern of highly used CT practices in DP1, MS3, PS1, and PS5. More CT practices of DP3(missing), DP4(missing), and DP5(missing) were developed and added and this improved STEAM program could give students chances to experience more extended CT practices as envisioned ones.

The following are samples of suggestions how CT practices could be improved from weakly to strongly exposed in the engineering focused STEAM programs. The first sample is from Engineering 1 whose title is *'create automated devices for safe living from natural disasters and man-made disasters'* (Table 31).

Table 31. The improvement of CT practices by adding the activity in engineering STEAM program.

Engineering 1: Create Automated Devices for Safe Living from Natural Disasters and Man-made Disasters
CT practices improved in this module: MS1 + MS2
The Introduction of the Module *This module is composed of eight lessons, "What are Disasters and How Can We Overcome Them" is lesson 1. Lessons 2 and 3 are grouped and are called "Science and Technology Challenge for Disaster and Disaster Alarm". Lessons 4 to 7 are called "Creating an*

Automated Disaster Alarm", and lesson 8 is called "An Exhibition Hall of the Classes Work". This is the lessons were designated in the original module.

The Context of the Lesson

The module starts with an introduction of the students reading about the damage caused by an earthquake in Japan. They then read a passage that introduces the idea of natural and man-made disasters and how technology might be used to to reduce the damage caused by disasters. Lesson 1 starts with the students watching some disaster movie trailers and considering some questions about what is a disaster, how do disaster affect human life, and what is the relationship between technology and disasters. The lesson then continues with a more indepth look at the different ways that technology can be used to help during a disaster.

Original Activity in the lesson

[Open your thought]

Overcoming Natural and Man-made Disasters Using Science and Technology

The following shows the area where science and technology are used to overcome natural and man-made disasters.

Choose one of the natural and man-made disasters and think about how technology can be used to overcome it.

➔ Group selected disasters.

Prevention	*Prediction*	*Detect*	*Relay*	*Restore*

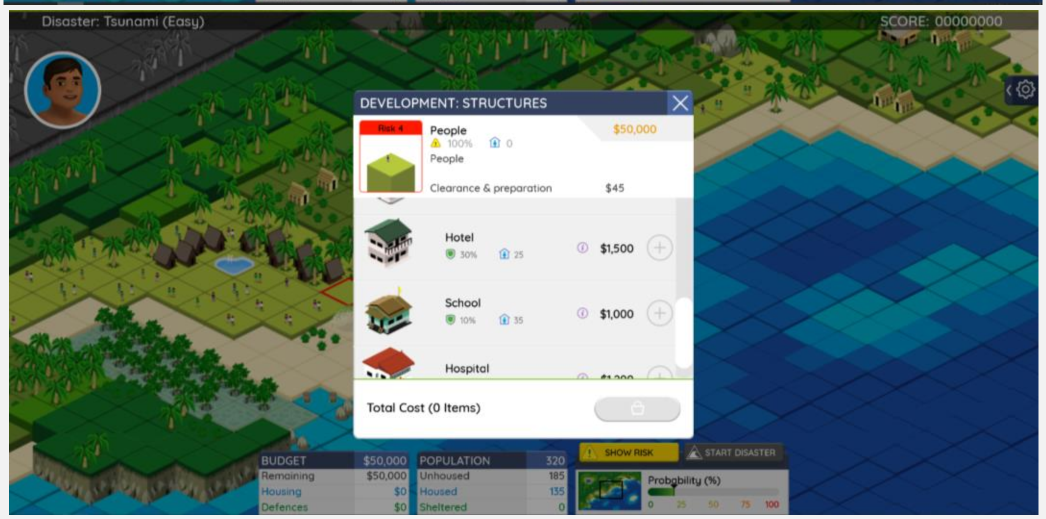
How to improve CT practice

The suggested activity would be done by the students after the activity shown above. The purpose of the suggested activity is to give the students the chance to use some computational models to understand how different strategies and technology can be used to protect and reduce the damage from disasters. The desktop game is from www.stopdisastersgame.org, which was developed by The United Nations for Disaster Risk Reduction (UNDRR). From the UNDRR's website, "It enables players to experience 5 natural environmental hazards (wildfires, earthquakes, floods, tsunamis, and hurricanes). Learn of the risk posed by natural hazards and manage your resources. Build schools, hospitals, housing and defenses to protect the local population." (playerthree and UNDRR, 2018).

Suggested Activity in the lesson

Can you protect against a disaster?

You are going to use the UN's disaster simulator to see if you can protect the people from a disaster. There are 5 different disasters to try; wildfires, earthquakes, floods, tsunamis, and hurricanes. Pick one of the disaster simulations you would like to try and choose the easy difficulty. Try to follow the directions and get the highest score you can? ***<u>(MS1 skill added)</u>***



Now you learnt the basics try a new disaster and this time raise the difficulty level to medium or hard. Can you still complete the objectives and save everybody from the disaster? ***<u>(MS2 skill added)</u>***

The above engineering focus STEAM program has the pattern of highly used CT practices in MS3, PS1, and PS5 mainly. More CT practices of MS1(missing) and MS2 (missing) were developed and added and this improved STEAM program could give students chances to experience more extended CT practices as envisioned ones. The following sample is from Engineering 2 whose title is *'science story at the airport and airplanes'* (Table 32).

Table 32. The improvement of CT practices by adding the activity in engineering STEAM program.

Engineering 2: Science Story at the Airport and Airplanes

CT practices improved in this module: PS2

The introduction of the module (3 lessons)

This module is composed of three lessons, "Places to Get on the Plane" is lesson 1. Lessons 2 and 3 are called "How Can I Float an Object" and "Airplane, the Secret of Center of Gravity" respectively.

The context of the 1st lesson

Lesson 1 is split into two sections. The first section is the students learning about what items are prohibited on airplanes. They watch videos and then answer questions and do a cloze exercise to check their understanding. They then learn why items such as a ball are banned due to the explosive expansion caused by pressure differential. Next is a group presentation about in-flight prohibited items with peer evaluation.

The second section is concerned with the different checkpoints that people pass through in an airport. The students start by learning about the history and role of security checkpoints. The next activity is the students constructing their own metal detectors using a kit and then trying to find an object hidden by their partner. Activity 3 is the students considering how checkpoints should be arranged in an airport to have effective security while minimizing passenger discomfort. The section and lesson 1 finishes with some reading material about prohibited items and the difference between x-rays and t-rays.

Original Activity in the lesson

[Activity 3] Today and Tomorrow at Airport Checkpoint

1. Consider aviation safety, but minimize passenger inconvenience! (Locating the airport's checkpoints)

Metal detectors can detect weapons such as pistols. But not all metal products can be banned to prevent weapons. Design an airport checkpoint that can effectively protect aviation safety while minimizing passenger discomfort. Considering the 'places you'll need to go through to get to the plane,' you learned earlier, let's divide the airport search into several roles and arrange them along the passenger's route.

☞

☞

2. Ways to look inside without opening the luggage.
- Review the background and progress of the airport search stations, (see Read 2), and consider the role of science.

☞

☞

How to improve CT practice

The suggested activity would be done by the students as part of the activity shown above. The purpose of the suggested activity is to give the students the chance use an algorithm to stimulate a logical approach to the designing of the airport checkpoints.

Suggested Activity in the lesson

1. Consider aviation safety, but minimize inconvenience!

Metal detectors can detect weapons such as pistols. But not all metal products can be banned to prevent weapons. Design an airport checkpoint that can effectively protect aviation safety while minimizing passenger discomfort. Considering the "places you'll need to go through a plane," you've learned earlier, let's divide the airport search into several roles.

☞

☞

Now you have considered what checkpoints are needed, make a flowchart to show the layout of the checkpoints in an airport. ***(PS2 skill added)***

The above engineering focus STEAM program has the pattern of highly used CT practices in DP1, DP5, MS1, MS2, and PS5. A CT practice of PS2 (missing) was developed and added and this improved STEAM program could give students chances to experience more extended CT practices as envisioned ones. The next sample is from Engineering 3 whose title is *'where is the fine dust?'* (Table 33).

Table 33. The improvement of CT practices by adding the activity in engineering STEAM program.

Engineering 3: Where is the Fine Dust?

CT practices improved in this module: MS5 + PS2 + PS6

The introduction of the module (2 lessons)
This module is composed of two lessons, "What and Where is the Fine Dust?" is lesson 1. Lessons 2 is called "Can We Reduce Fine Dust?".

The context of the 1st lesson
Lesson 1 is split into 7 sections and is longer than lesson 2. The lesson starts with the students reading about what fine dust is, how it is generated and then do a quiz. The students then search the internet to find out about the dust concentration around Korea. Then they do an experiment to measure the fine dust levels in their own neighbourhood.

Original Activity in the lesson

Open Your Mind

Measure Fine Dust!

What you need: fine dust meter

- ☑ Fine dust is measured twice at 1 minute intervals from the set time.
- ☑ Photograph the place where the fine dust is measured and write a description.
- ☑ Time is 25 minutes.

- Team: ________________________________
- Date and Time: ____________________________

Measuring Place	Description of the Measuring Place (e.g. lunch room)	Measurement Time	Fine Dust Measurement Value (μg / m^3)	

How to improve CT practice

The suggested activity would be a modified version of the activity shown above. The purpose of the suggested activity is to give the students the chance to experience programming. The importance of having students experience programming is an important part of a 21st century education. The suggested activity using Arduino is a good way to introduce the basics of programming.

Suggested Activity in the lesson

Open Your Mind

Measure Fine Dust

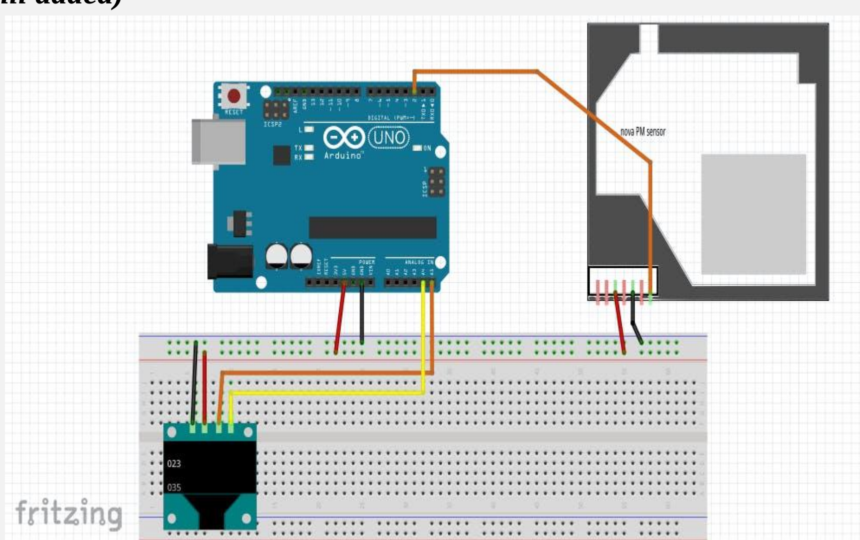
What you need: Fine dust sensor (Nova PM SDS011), Arduino, Graphic Display

- ☑ Fine dust is measured twice at 1 minute intervals from the set time.
- ☑ Photograph the place where the fine dust is measured and write a description.
- ☑ Time is 25 minutes.

- Team: ____
- Date and Time: _________________________________

1) First we need to setup the measuring equipment. Setup your group's Arduino as follows:

(MS5 skill added)



2. Download the easy to learn programming language Python (www.python.org).
3. 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 fine dust project". ***(PS2 skill added)***
4. If your RSS feed doesn't work, check these 3 things to find the mistake. ***(PS6 skill added)***

a) Check the port in the python file. Your Arduino may be labeled differently or be numbered differently.
b) Check that the RSS feed doesn't have a ~ in the data.
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.
(Arduino set-up and programming taken from https://create.arduino.cc/projecthub/plouc68000/portable-fine-dust-pm10-analyzer-with-large-oled-digits-1c20c2)

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The above engineering focus STEAM program has the pattern of highly used CT practices in DP1, DP4, DP5, PS1, and PS5. More CT practices of MS5(very weakly exposed), PS2(missing), and PS6(missing) were developed and added and this improved STEAM program could give students chances to experience more extended CT practices as envisioned ones. The next sample is from Engineering 4 whose title is *'ecological drone use'* (Table 34).

Table 34. The improvement of CT practices by adding the activity in engineering STEAM program.

Engineering 4: Ecological Drone Use
CT practices improved in this module: DP5
The introduction of the module (2 lessons) This module is composed of two lessons, "Fading Animals, Plants and the Future of Humanity" is lesson 1. Lessons 2 is called "Ecological Models". **The context of the 1st lesson** Lesson 1 starts with the students learning about ecosystem destruction and species extinction and the impact that can have on peoples' lives and efforts to protect ecosystems and animals. The students then consider what measures they would take to help the specific example of the

otter. The students then watch a video to see how technology, and in particular drones, can help restore ecosystems.

Original Activity in the lesson

4-1 Explore Ecology Around Us

⇛ Let's find out about the ecology around us. Encyclopedias (books, smartphone apps), using the Internet to browse and write the contents briefly.

[picture – google image]


[picture – https://pixabay.com]


picture – google image]

Find Out	Search Method	What Did You Find?

How to improve CT practice

The suggested activity would be performed after the activity shown above. The module has many examples of data collection but there is no instances of data analysis. The following questions are therefore designed to have the students consider and analyze the data they collected from different sources. The analysis of the data would also appropriately lead the students into the follow activity. The next activity asks the students to think what ecosystem they are most interested in, the characteristics of that ecosystem, and making a model of the ecosystem

Suggested Activity in the lesson

Look again at the information you collected from the various sources.

⇛ How many different ecosystems did you find in the surrounding area? ***(DP5 skill added)***

⇛ Which ecosystem do you think is in the most urgent need of help? ***(DP5 skill added)***

⇛ Are there any ecosystems that do not appear to be in danger at present? ***(DP5 skill added)***

The above engineering focus STEAM program has the pattern of highly used CT practices in DP1, MS4, PS1, PS2, and PS5. A CT practice of DP5 (weakly exposed) was developed and added and this improved STEAM program could give students chances to experience more extended CT practices as envisioned ones. The next sample is from Engineering 5 whose title is *'automata bearing safety'* (Table 35).

Table 35. The improvement of CT practices by adding the activity in engineering STEAM program.

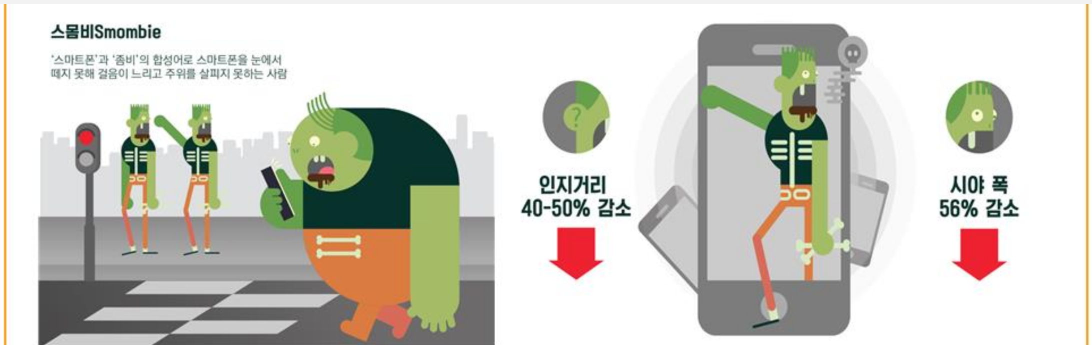
Engineering 5: Automata Bearing Safety
CT practices improved in this module: MS2
The introduction of the module (2 lessons) This module is composed of four lessons, "Pre-learn About Automata" is lesson 1. Lessons 2 is called "Navigating Safety Incidents, Expressions of Tools". Lesson 3 is titled "Build a Safe Automata" and lesson 4 is called "We are Safe Guards". **The context of the 1st lesson** Lesson 1 starts with a pre-learn activity and the students watching a video about safe automata programs and writing down what they learn. They then watch a flip learning video and try to answer some questions. One of those questions is asking the students to name eight different machine elements. The first hour (1 차시) has the students watch a video about the risks and prevention of bicycle accidents. They then have a group activity. The group discusses seven different safety zones and then decides which topic they would like to do base their group project on. The first hour concludes with the following activity about Smombies.

Original Activity in the lesson
Automata's Media Story

Are You a Smombie?

The following is a newspaper article about Smombies that has recently emerged as a headache for traffic safety. Read the following and feel the importance of the practice of safety accident prevention and prevention.

As you climb the stairs and cross the predestrian crossing, you only see your smartphone. I'm not interested anywhere else, focusing my eyes on a small screen that's just six inches. Ears plugged with earphones do not hear any sound. It's called 'smombie' (a compound word of smartphone + zombie). As smartphones become an important part of everyday life, their side effects are raised. According to a survey by the Korea Road Traffic Safety Authority, predestrian accidents involving smartphones more than doubled from 624 in 2011 to 1360 in 2016. In addition, 95.7% of smartphone users used smartphones while walking, and 21.7% said they had accidents.



<스몸비의 정의> <Definition of sumobi> <스몸비의 교통 안전사고의 위험성> Risk of Traffic Safety Accidents
출처 : SBS 뉴스, 보행 중 사고 급증…도로표지판에 나타난 '스몸비', 2016.12.07.,
https://news.sbs.co.kr/news/endPage.do?news_id=N1003925565&plink=COPYPASTE&cooper=SBSNEWSEND

How to improve CT practice

The suggested activity would be performed after the activity shown above. This module has no instances of MS2 and so the following activity is designed to introduce that skill. The suggested activity gives the students the chance test their understanding of the concept and dangers of being a smombie.

Suggested Activity in the lesson

- We are now going to see how difficult it is to notice objects and details when you are concentrating on your smartphone.
- You are going to walk down a path between your classmates standing on the sides of the path. Your classmates are going to hold up pieces of paper with different letters written on them. You are going to walk down the path writing a message on your smartphone. You can only look at the smartphone but try to see

how many letters you can identify as you walk down the path.

- How many letters do you think you will be able to correctly identify? ***(MS2 added)***

The above engineering focus STEAM program has the pattern of highly used CT practices in DP1, PS3, and PS5. A CT practice of MS2 (missing) was developed and added and this improved STEAM program could give students chances to experience more extended CT practices as envisioned ones.

4.2.2 Analysis of Results 2

The researcher was able to suggest an activity to reinforce the weakly exposed or missing practice for each module. In this way, the researcher can improve CT practices to be more exposed with the use of CT analyzing tool developed in this study. This result demonstrates that current STEAM programs can be improved with more explicit CT practices included so that STEAM education could meet the vision of creative problem solvers needed in the 21st century.

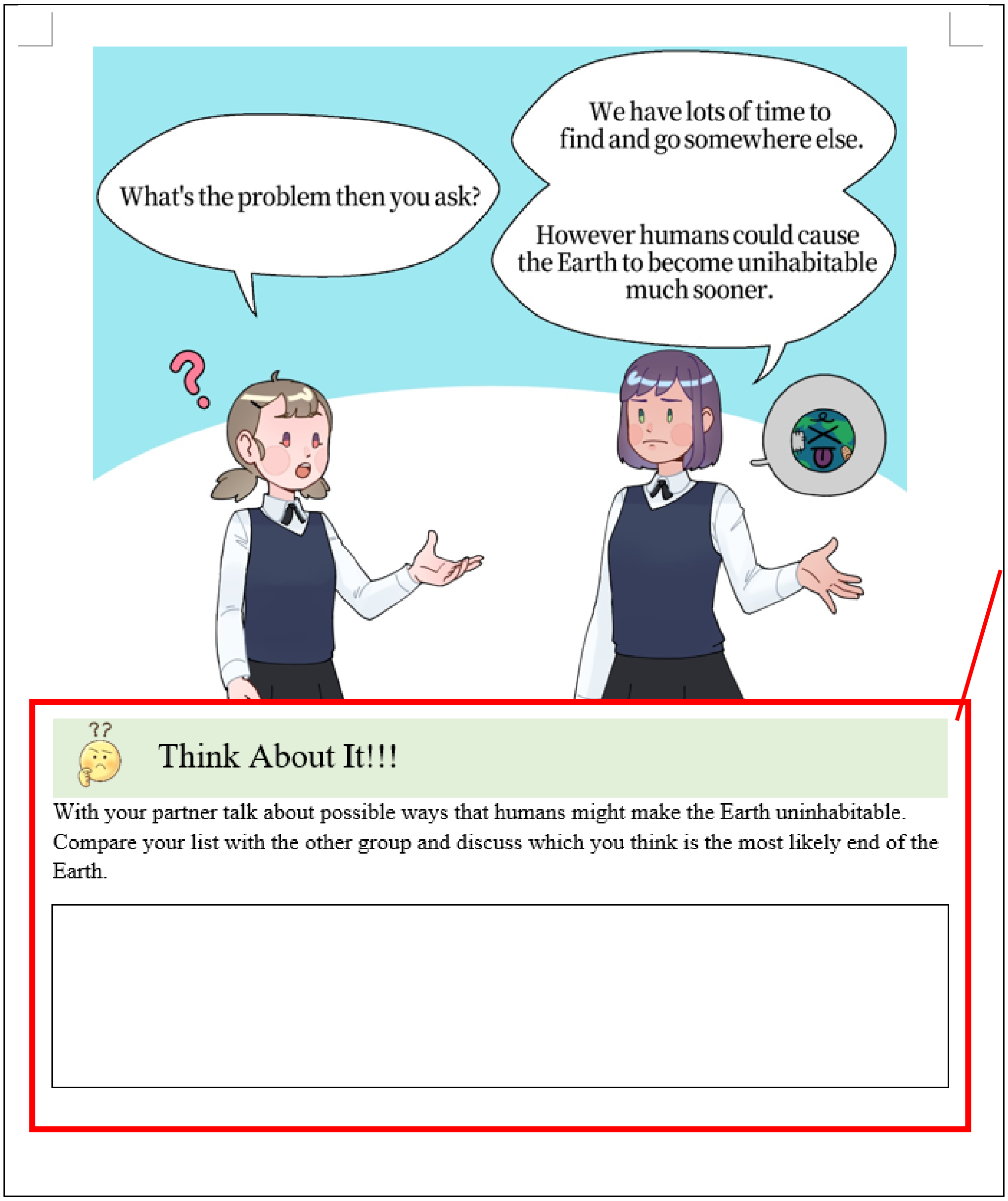
4.3 Results 3: Developing STEAM Programs

4.3.1 Developing a STEAM module

In this section the researcher will answer the third research question of designing a STEAM module to systematically maximize the instances of CT practices. The researcher's developed module can be found in the appendix. Following is the analysis of the module. The instances of CT practice are highlighted in red boxes and then a description of the practice is given. The analysis is contained in tables 36 to 55.

4.3.2 Analysis of the Developed Computational Module – 'Where Can We Go and How Can We Live There if the Earth Becomes Uninhabitable?'

Table 36. Analysis of Page 3: Opening Thoughts



PS1:
This 'Think About It' is an example of PS1 (Preparing Problems for Computational Solutions) as the students are decomposing the idea of the Earth becoming uninhabitable into the different events/causes of the end of the world.

Table 37. Analysis of Page 4: Lesson 1 Opening Thoughts

<u>PS5:</u>
This 'Think About It' is an instance of the PS5 practice (Creating Computational Abstractions). The students are considering the term "climate change" and deciding what is important to them in its meaning.

Lesson 1: Why We Might Need to Leave?

Lesson 1 Opening Thoughts: What Disastrous Event Might Happen?

There are many possible ways that all human live on Earth might be in danger.

Nuclear War	Global Pandemic	Meteor Strike

In this lesson we are going to look at a different event that might put humans in danger, climate change.

Think About It!!!

With your partner/group discuss what the term climate change means to you.

Table 38. Analysis of Page 5: Lesson 1 Activity 1

Activity 1: The Warming Earth?

One of the most scientifically accepted ways that humans might make the Earth uninhabitable is by the rise in global temperatures. In this activity we are going to look at how the global temperature is changing both short-term and long-term.

As we are going to look at the temperature over such a long period of time each group is going to plot a 20-year period and then we will combine all the groups work to see the complete long-term pattern.

Think About It!!! PS3

As we are going to combine all the graphs together we need to all use the same style and scale. In your group decide which of 'temperature' and 'year' should be the x-axis and which should be the y-axis. You should also decide the scale of each axis.

PS3:
This activity is PS3 (Choosing Effective Computational Tools). The students are making decisions about the parameters of the graph, such as style, scale, and labelling of each axis.

Think About It!!! PS5

Now that the class has decided on the axis and scale what do you predict will be the result? Write down what your group thinks the graph will look like and why? Will there be an increase or decrease in temperature, or will it stay almost the same?

PS5:
This 'Think About It' is considered to be the PS5 (Creating Computational Abstractions) practice. The students are considering the factors that they know with regards to the possible changing of the temperature on Earth. They are then making predictions about what they think the results will show.

Table 39. Analysis of Page 6: Lesson 1 Activity 1 (continued)

DP1 + DP5:
This activity displays the DP1 (Collecting Data) and DP5 (Visualizing Data) practices. It is DP1 as the students are going to the website to download the temperature data. They then add this data to their graph (either by hand or with a graphing tool) which is the DP5 practice.

☞ Now we need to collect the data. You can go to the NOAA (National Oceanic and Atmospheric Administration) website (https://www.ncdc.noaa.gov/cag/global/time-series) to find the data for your group's time period. The data gives the temperature anomalies (difference) with respect the 20th century average. A positive number means the temperature was warmer than the average. A negative number means the temperature was colder than the average. Add you collected data to your graph. DP1 + DP5

Think About It!!!

What does the data show? DP4

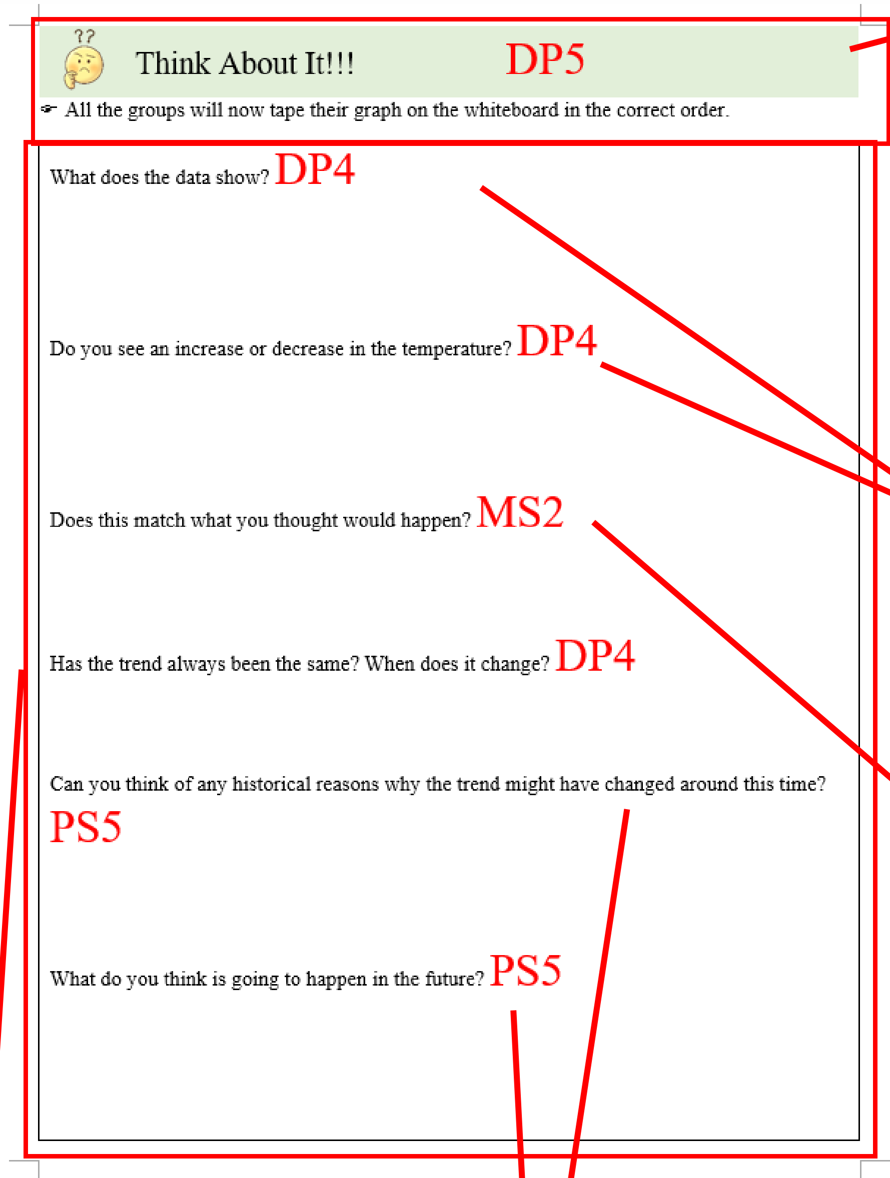
Do you see an increase or decrease in the temperature? DP4

Does this match what you thought would happen? DP4

Do you think that when we look at the complete graph it will look the same as your group's graph? DP4

DP4:
This activity is four instance of the DP4 (Analyzing Data) practice. The students are studying the data on the graph to answer the four questions.

Table 40. Analysis of Page 7: Lesson 1 Activity 1 (continued)



DP5:
This is the DP5 (Visualizing Data) practice. The students are combining the individual groups' data to create a graph for the entire time period.

DP4:
These two activities are DP4 (Analyzing Data) The students are studying the data to answer the questions.

MS2:
This activity is MS2 (Using Computational Models to Find and Test Solutions. The students are seeing if their proposed solutions matches the data.

DP4:
This activity is DP4 (Analyzing Data) The students are studying the data to answer the question.

PS5:
These two activities are PS5 (Creating Computational Abstractions). The students are simplifying their pre-knowledge of history to look for historical factors about the change in temperatures and predicting about the future.

Table 41. Analysis of Page 8: Lesson 1 Activity 2

Activity 2: What Does a Raising Temperature Mean for the Earth?

As the temperature of the Earth rises more and more of the ice at the poles will melt. This means that the sea level will rise. Most estimates says that the water will rise by at least 2 metres by the end of the century, which means about 200 million people will find their homes underwater. If all the ice melts then the water will rise by about 70 metres.

☞ We are going to make a model of the greenhouse effect. Many people around the world know what the greenhouse effect is, and almost everybody thinks it is a very bad thing. But the greenhouse effect is natural and in fact we need it. Without the greenhouse effect the average temperature of the Earth would be -18°C and no live would be possible. However because of the greenhouse effect our Earth has a pleasant average temperature of 14°C. The problem therefore is that we are increasing the effect of the greenhouse too much.

☞ Using the modelling clay make a model of a coastline or island in the aluminium tray. Try to make some mountainous areas and lowland areas. You should also make an area representing a city or group of houses on the lowland. MS5

☞ Pour in the water that the teacher gives you. Make sure you don't pour too much in!!

☞ Put the block of ice that the teacher gives you on the tallest part of your clay model. Then cover the model with a layer of plastic wrap. The plastic wrap is modelling the greenhouse gases in the atmosphere. Put your model in a warm (but not too hot) place.

MS1

MS5:
This activity is MS5 (Constructing Computational Models). The students are constructing a model of a land mass with some ocean or water.

MS1:
This activity is MS1 (Using a Computational Model to Understand a Concept). The students are using a plastic wrapped model with some ice to simulate the greenhouse effect and observe what will happen with rising sea-levels.

Table 42. Analysis of Page 9: Lesson 1 Activity 2 (continued)

Think About It!!!

What do you think is going to happen to the model? MS2

The teacher also made a model but didn't cover it with plastic wrap. Do you think the ice in the teacher's model will melt faster or slower than in yours? MS2

Measure the amount of water in the models regularly. Whose ice melts faster?
DP1 + DP4

Lesson 1 Closing Thoughts: Self-Evaluation

What is being evaluated?	Rating Scale			
	Excellent	Good	Average	Poor
What issue(s) is investigated in this lesson: ______				
What is your understanding of the issue(s) presented in this lesson?				
What is your scientific understanding of the issue(s)?				
What is your understanding of what will happen in the future with regards to the issue(s) of this lesson?				

9

MS2:
This activity is MS2 (Using a Computational Model to Find and Test Solutions). The students are using their model to observe if solution about what will happen with the greenhouse effect matches the result. They are also seeing is their belief about the differences between the covered and uncovered models are true.

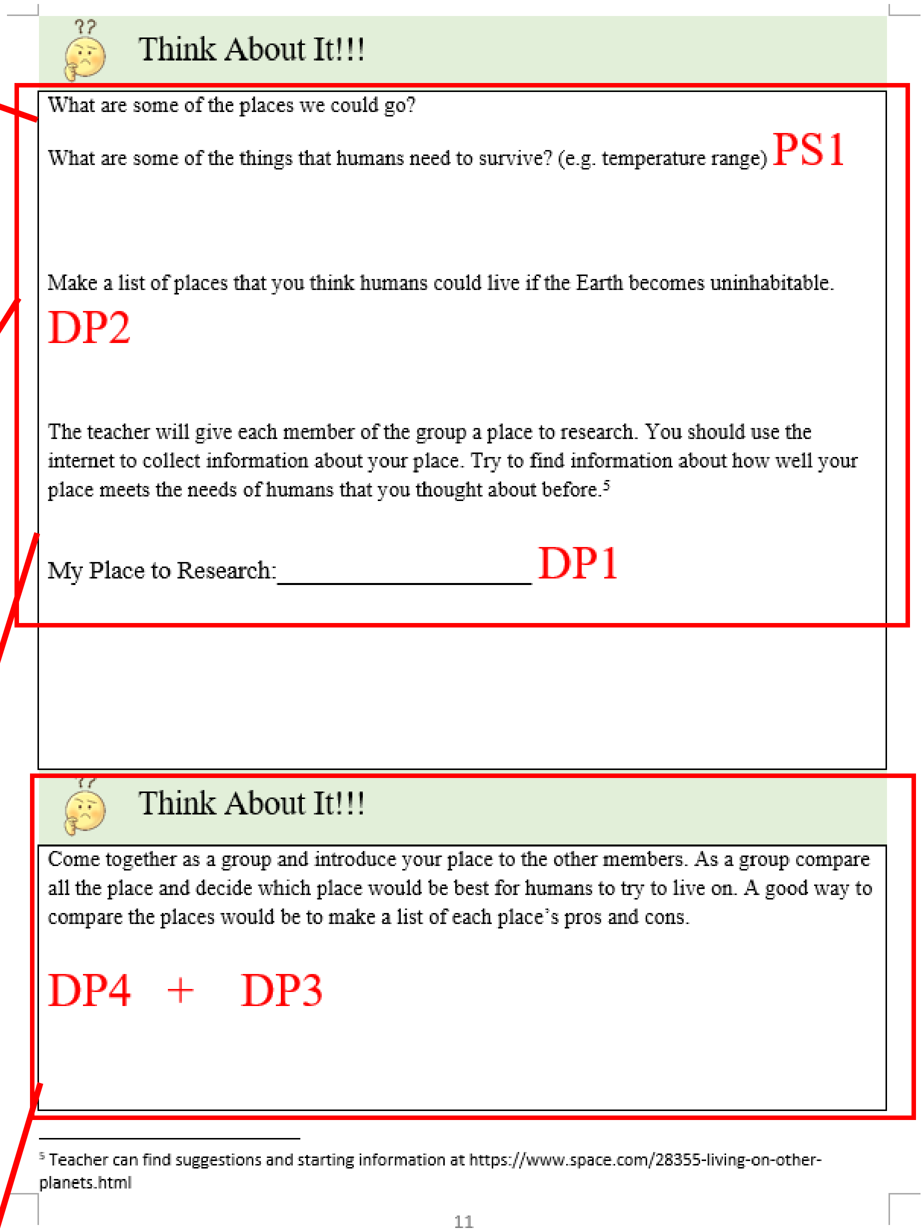
DP1 + DP4:
This activity displays the DP1 (Collecting Data) and DP4 (Analyzing Data) CT practices. The students are measuring the changing water level and analyzing which model's ice melts the fastest.

Table 43. Analysis of Page 11: Lesson 2 Activity 1

PS1:
This is PS1 (Preparing Problems for Computational Solutions). The students are decomposing the issue of human survival into what factors affect human survival.

DP2:
This is DP2 (Creating Data). The students are creating a list of possible places their think humans could make a successful colony.

DP1:
This is DP1 (Collecting Data). The students are collecting information about their assigned place.



Think About It!!!

What are some of the places we could go?

What are some of the things that humans need to survive? (e.g. temperature range) PS1

Make a list of places that you think humans could live if the Earth becomes uninhabitable.

DP2

The teacher will give each member of the group a place to research. You should use the internet to collect information about your place. Try to find information about how well your place meets the needs of humans that you thought about before.[5]

My Place to Research:___________________ DP1

Think About It!!!

Come together as a group and introduce your place to the other members. As a group compare all the place and decide which place would be best for humans to try to live on. A good way to compare the places would be to make a list of each place's pros and cons.

DP4 + DP3

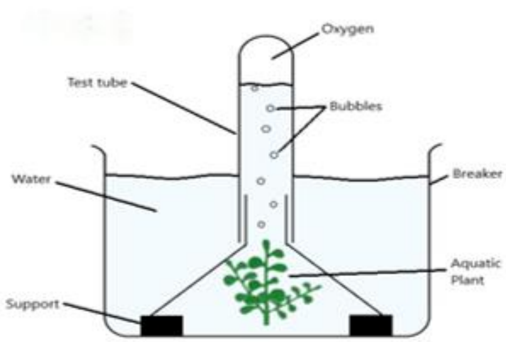
[5] Teacher can find suggestions and starting information at https://www.space.com/28355-living-on-other-planets.html

11

DP4 + DP3:
This activity is DP4 (Analyzing Data) and DP3 (Manipulating Data). The students analyzing their individual data as a group and deciding what the best place for their colony is. They make this decision by manipulating the data into a list of pros and cons.

Table 44. Analysis of Page 13: Lesson 2 Activity 1 (continued)

✒ We are going to do an experiment to show how plants can be used to generate the oxygen we will need for our colony. The equipment is setup as follows:



Tips for a successful experiment

» You will need to mix in some baking soda to the water to make a sodium bicarbonate solution. This will provide the plant with the carbon dioxide it needs for photosynthesis.

» When turning over the test tube make sure it full of water. You will need to put your thumb over the top to stop the water falling out.

» Put some supports under the funnel to allow the sodium bicarbonate solution to circulate properly around the plant.

MS5

MS5:

This activity is MS5 (Constructing Computational Models). The students are setting up the equipment to conduct the experiment. This experiment is to demonstrate the how the process of photosynthesis generates oxygen as a byproduct.

Table 45. Analysis of Page 14: Lesson 2 Activity 1 (continued)

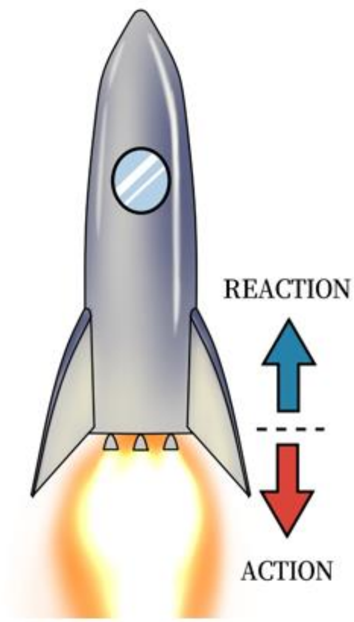
Think About It!!!
How do we know that oxygen was produced? We know that things burn easily in the presence of oxygen. So if a smoldering match bursts into flames we know we have oxygen. ☞ Slowly take the test tube off the funnel and while it is still in the water put your thumb over the end so the water and oxygen don't escape. With your thumb still over the end turn it the right way up so that the oxygen is at the top. ☞ Your partner should light a match and then quickly blow it out, so it is still smoldering. Take your thumb off the test tube and have your partner put the smoldering match in the test tube (be careful not to touch the water).

Think About It!!!
What happened to the match and what does that mean we can say about photosynthesis? MS2

MS2:

This activity is considered to be MS2 (Using Computational Models to Find and Test Solutions). The students introduce a lit match to the gas they collected in the experiment to try and demonstrate that it is oxygen that was generated by the plant.

Table 46. Analysis of Page 17: Lesson 3 Opening Thought



As the hot gas is ejected out of the bottom of the rocket there is a reaction force that sends the rocket shooting up into the air.

Think About It!!!

✑ To launch 1kg into space it costs about $18,000!!! Why do you think it is so expensive? What needs to be bought to launch that 1kg into orbit around the Earth?

PS5

PS5:
This activity is PS5 (Creating Computational Abstractions). The students are considering what factors are important for why it is so expensive to launch objects into Earth orbit.

Table 47. Analysis of Page 18: Lesson 3 Opening Thought (continued)

☞ If you have ever seen video of a rocket launch you may have seen some parts of the rocket break away and fall back to Earth. This type of rocket is called multi-stage. Below you can see an illustration of a stage of rocket breaking off and falling back to Earth.


[7]

☞ Why do you think people use this multi-stage type of rocket? What is the big advantage?

PS5

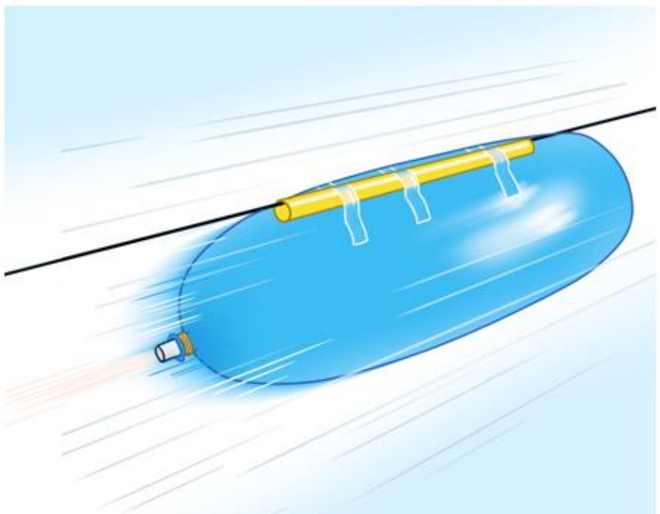
PS5:

This activity is considered to display the PS5 (Creating Computational Abstractions) practice. The students are decide what factors would be important for a rocket launch and deciding why a multi-stage rocket would be more efficient than a single-stage rocket.

Table 48. Analysis of Page 19: Lesson 3 Activity 1

Activity 1: Can we make a Model of a Multi-Stage Rocket?

☞ We are going to use balloons to make the model of our rocket. The air rushing out of the open end of the balloon is a good representation of the hot gases exploding out of the bottom of a launching rocket.



1. First blow up a balloon. It is best not to inflate it too fully. Just hold the end shut. DON'T TIE IT.
2. Put the end of the balloon through the ring and hold the end against the side.
3. Put another balloon about halfway through the ring and blow it up. You should blow it up enough so that it presses the end of the first balloon against the side of the ring. You should be able to let go of the first balloon without the air escaping. This can be difficult and you will find it easier to work in pairs. DON'T TIE EITHER BALLOON.
4. Tape the balloons to the straws that your teacher has setup for you.

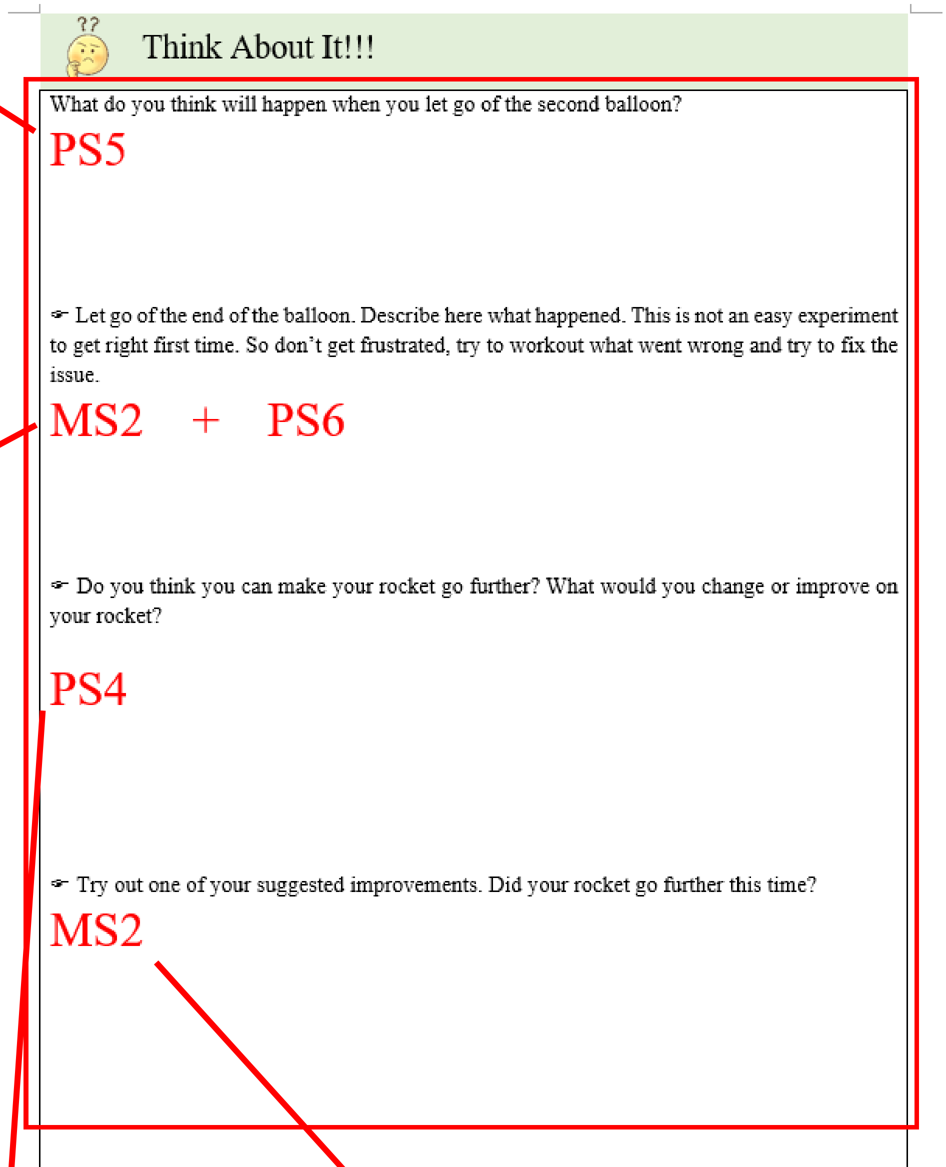
MS5

19

MS5:

This activity is MS5 (Constructing Computational Models). In this activity the students are following the instructions to setup the experiment to demonstrate the benefit of using a multi-stage rocket rather than single-stage rocket.

Table 49. Analysis of Page 20: Lesson 3 Activity 1 (continued)



Think About It!!!

What do you think will happen when you let go of the second balloon?

PS5

☞ Let go of the end of the balloon. Describe here what happened. This is not an easy experiment to get right first time. So don't get frustrated, try to workout what went wrong and try to fix the issue.

MS2 + PS6

☞ Do you think you can make your rocket go further? What would you change or improve on your rocket?

PS4

☞ Try out one of your suggested improvements. Did your rocket go further this time?

MS2

PS5:
This is PS5 (Creating Computational Abstractions). The students are deciding what factors are important to decide what will happen.

MS2 + PS6:
This is MS2 (Using Computational Models to Find and Test Solutions) and PS6 (Troubleshooting and Debugging). The students let go of the balloon to observe if it matches their expectations. Getting the experiment to run correctly is difficult and so the students will probably have to solve some technical issues.

PS4:
This is PS4 (Assessing Different Approaches / Solutions to a Problem). The students are considering different ways to make their rocket travel further.

MS2:
This is MS2 (Using Computational Models to Find and Test Solutions). The students are trying out their proposal to make the rocket travel further to see if they are successful or not.

Table 50. Analysis of Page 22: Lesson 4 Opening Thoughts

Lesson 4: What Does Your Colony Need to Thrive?

Lesson 4 Opening Thought: What do Humans Need to Survive?

In lesson 2 we talked briefly about what humans need to survive. Let's look at some of the issues that would need to be addressed for humans to survive on a colony on another planet. We are going to look at three very important things that humans need, oxygen, water, and food. We want our colony to last for a very long time so we need to think of a way to produce or find all three.

Oxygen:

Humans need oxygen to breathe. Oxygen is a fuel our cells need to survive. Oxygen is an important building material for our bodies. Oxygen together with nitrogen and hydrogen make proteins that are used as a construction material for our cells. To make carbohydrates, the source of energy in our bodies, oxygen is combined with carbon and hydrogen.

In lesson 2 we saw that one possible way to produce oxygen is by the process of photosynthesis. There are, however, other ways to get the oxygen we need. NASA has developed a technology called MOXIE which is being tested on the Mars Perseverance rover. MOXIE uses electrolysis as well but uses the carbon dioxide of the Mars atmosphere to get its oxygen. Getting our oxygen from electrolysis will work but both ways require technology, and technology can breakdown. So is there a way to get our oxygen without technology. Yes, we can use the same way we get oxygen on Earth, plants. Plants generate oxygen through the process of photosynthesis. The problem with growing the plants is we need to make the soil fertile for them. Microbes can do this but it will take a long time.

Think About It!!! PS3

Which way do you think would be best for us to get the oxygen we need?

22

PS3:

This is the PS3 (Choosing Computational Tools) practice. The students are using their learnt knowledge from lesson 2 to decide the best tool to generate the oxygen that the colony will need.

Table 51. Analysis of Page 23: Lesson 4 Opening Thoughts (continued)

Water:

Water keeps our bodies healthy in many ways. Water is very important for in the process of food digestion, keeps body temperature normal, it also helps protect our joints, and our blood is about 90% water. It also keeps our brain working well. That's why doctors recommend we drink lots of water every day. The numbers vary but most doctors say we need about 10 to 15 cups of water every day.

There is water on Mars, but it is found as ice at both the north and south poles. We could melt this ice to drink but then the colony would need to be in these cold polar regions. It may also be possible to extract water from Mars atmosphere but surveys show there isn't much water present. It might also be possible to vapourise the water out of the Martian subsoil but it's possible there isn't any there to find.

Think About It!!! PS3

What do you think is the best way to get the water for a colony?

PS3:

This activity is the PS3 (Choosing Effective Computational Tools) practice. The students are making decisions about how they will find the water for their colony.

Table 52. Analysis of Page 24: Lesson 4 Opening Thoughts (continued)

Food:

Food is an important fuel for the human body. It is a source of nutrients, minerals, and vitamins. Humans can survive about 3 weeks without food, but as everyone knows we want to eat every day.

The oxygen and water can be found on Mars but there is no food. We have to find a way to grow our own. The soil does require some work to make it able to grow plants in, but it is possible for us to make the Martian soil suitable for growing plants. The choice is to decide which plants you would like to grow in your colony.

Plants are great as a food source but humans also need to have some way of getting protein in our diet. On Earth we get our protein by eating animals such as chickens, cow, pigs, etc. It will be very difficult (and expensive) to transport the animals from Earth to Mars. Many people think the solution is insects. Insects are a very good source of protein as they don't require much water or food for themselves. The problem is that many people think it's disgusting to eat bugs.

Think About It!!! PS3

What food do think people should eat in your colony?

PS3:
This activity is the PS3 (Choosing Effective Computational Tools) practice. The students are making decisions about how they will find the water for their colony.

Table 53. Analysis of Page 25: Lesson 4 Activity 1

MS4:
This activity is the MS4 (Designing Computational Models) practice. The students are designing and planning out their colony. Making choices about oxygen, water, and food generation, as well as, living space and entertainment.

Activity 1: Brainstorm what you want to take to your colony.

With your group think about you want to be present in your colony. Your group needs to consider things that your colony will definitely need, such as, how to generate the oxygen, water, food, a place to sleep, and energy. Your group should also think about things you would like you to have in your colony. Remember you need something to keep everyone entertained. MS4

Cut out pieces of papers to represent the different buildings and areas of land that you what to have in your colony. You should keep things to scale. You don't want your bed to be tiny and the bathroom to be half the size of the colony. It is possible to have more than one floor to your colony but think what should be on the bottom floor carefully. MS5

MS5:
This activity is MS5 (Constructing Computational Models). The students are now constructing their planned colony. This can be done to different levels depending on the time available. The students could make a physical model of their colony or they could draw out the plans on a piece of graphing paper.

Table 54. Analysis of Page 28: Lesson 4 Activity 2

Activity 2: Building a Rover for Your Colony

A rover is a very important tool for your colony. The rover can be used to scout the area for where you will be put your colony. You need to make sure the area is a good place for the colony.

Your teacher will provide your group with the kit to build your rover. MS5

MS5:
This activity is the MS5 (Constructing Computational Models) practice. The students follow the instructions to build their colony's rover. In the example pictured the student is using the Lego WeDo 2.0 Core Set. However, the activity can be conducted with the teacher choice of rover.

The course has been marked out with tape on the table. Your group should program your rover to follow the course. Your team will lose points for going over the lines of tape.

PS2

PS2:
This activity displays the PS2 (Programming) practice. The students use the Lego WeDo app to develop a program to control their rover. There are a number of different modes for the students to experiment with. There is a simple move forwards and backwards, search for an object, to the allowing the student to design their own program.

Table 55. Analysis of Page 29: Lesson 4 Activity 3

PS4:

This activity is considered to be the PS4 (Assessing Different Approaches / Solutions to a Problem) practice. The students are doing an exhibition hall to display their colony to the other student groups and also to observe those groups' colonies. They are judging the colonies on how well they achieve the needed solutions to the problem that the colony will face.

Activity 3: Exhibition Hall

Now it's time for the groups to present their colonies to the other groups. You should explain how to generate the oxygen, water, food, a place to sleep, and energy. Your group should also think about things you would like you to have in your colony. Remember you need something to keep everyone entertained. PS4

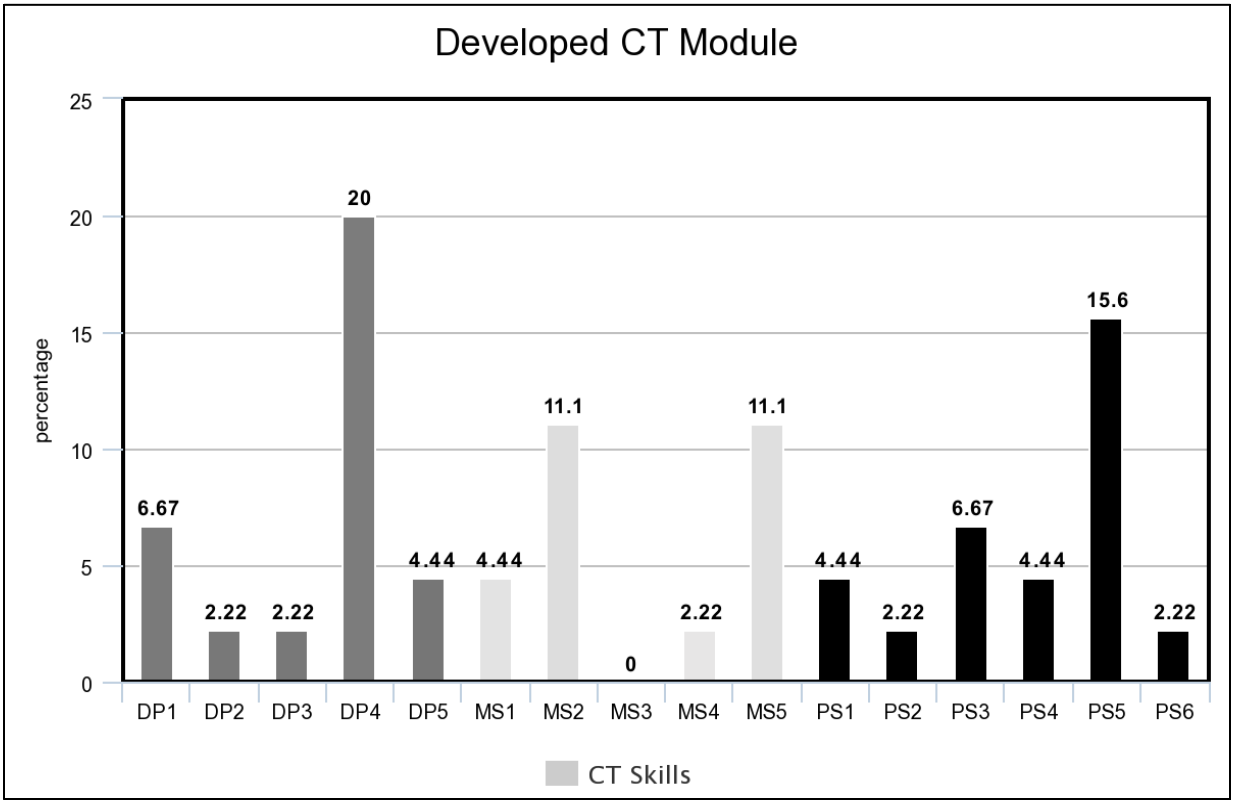
Group Members:					
Colony's Name:					
Source of Oxygen	①	②	③	④	⑤
Source of Water	①	②	③	④	⑤
Source of Food	①	②	③	④	⑤
Place of Shelter	①	②	③	④	⑤
Source of Energy	①	②	③	④	⑤
Extras for the Colony	①	②	③	④	⑤

Group Members:					
Colony's Name:					
Source of Oxygen	①	②	③	④	⑤
Source of Water	①	②	③	④	⑤
Source of Food	①	②	③	④	⑤
Place of Shelter	①	②	③	④	⑤
Source of Energy	①	②	③	④	⑤
Extras for the Colony	①	②	③	④	⑤

29

4.3.3 Analysis of Results 3

The pattern of CT practices in the developed STEAM program is displayed, whose title is 'Where Can We Go and How Can We Live There if the Earth Becomes Uninhabitable?' (Fig 30).



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 30. The pattern of CT uses in the develop CT module

A total of 45 CT practices were found in this module. There were 16 (35.6%) Data Practices, 13 (28.9%) Modelling and Simulation Practices, and 16 (35.6%) Computational Problem Solving Practices. The practices were fairly well evenly distributed between the three major categories, with slightly less Modelling and Simulation Practices than the Data Practices and Computational Problem Solving Practices.

The most commonly found practices was DP4 (Analyzing Data) with 20.0% or 9 /45 practices found in the module. 8 / 9 of the DP4 practices were found in the first of the four lessons as the students analyze the data of temperature changes to determine patterns and points of interest. The second most commonly found skill was PS5 (Creating Computational Abstractions) with 15.6% or 7 / 45 practices found in the module. 4 / 7 of the PS5 practices were found in the first lesson and 3 / 7 were found in the third lesson. An example of the PS5 practice in lesson 3 was the students being asked to consider the advantages of why a multi-stage rockets are more fuel efficient than single stage rockets. There was 1 example of a practice that recorded no instances, MS3 (Assessing Computational Models).

The third research question asked about what difficulties the researcher experienced when developing the CT module. 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 will encounter, creative decisions. After the creative 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 creative decisions and exposes the students to CT practices.

4.4 Results 4: Developing CT Practices Teacher Guideline

4.4.1 Analysis of STEAM Modules by Student Teachers

To validate the CT_AT two students were asked to use the analyzing tool to analyze two STEAM modules. These two students were chosen for their backgrounds in science, specifically science education, and their ability to converse with the researcher in English. They are both pursuing PhD qualifications in science education.

For the first stage of their analysis the student teachers were presented with three diagrams (Figures 31, 32, and 33). The diagrams detail the thought processes that the researcher went through when analyzing the STEAM modules himself. There are some general pieces of information written in black. This is some information about how commonly the researcher found the practice. Next, there is some hints and suggestions that could be useful for the student teachers to be more confident about choosing what practice to assign to an activity. The final pieces of information are written in red. This information is some warning and things to watch out for when analyzing STEAM modules.

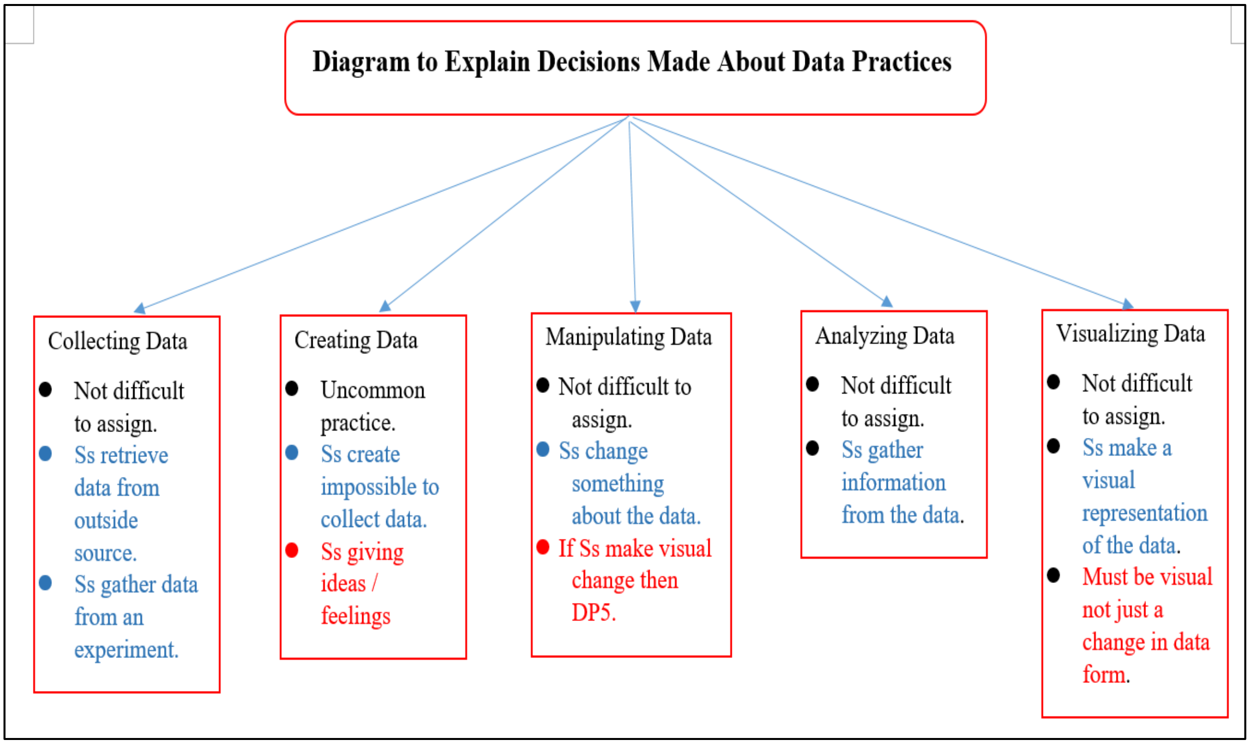


Figure 31. Diagram to explain decision about assigning Data Practices

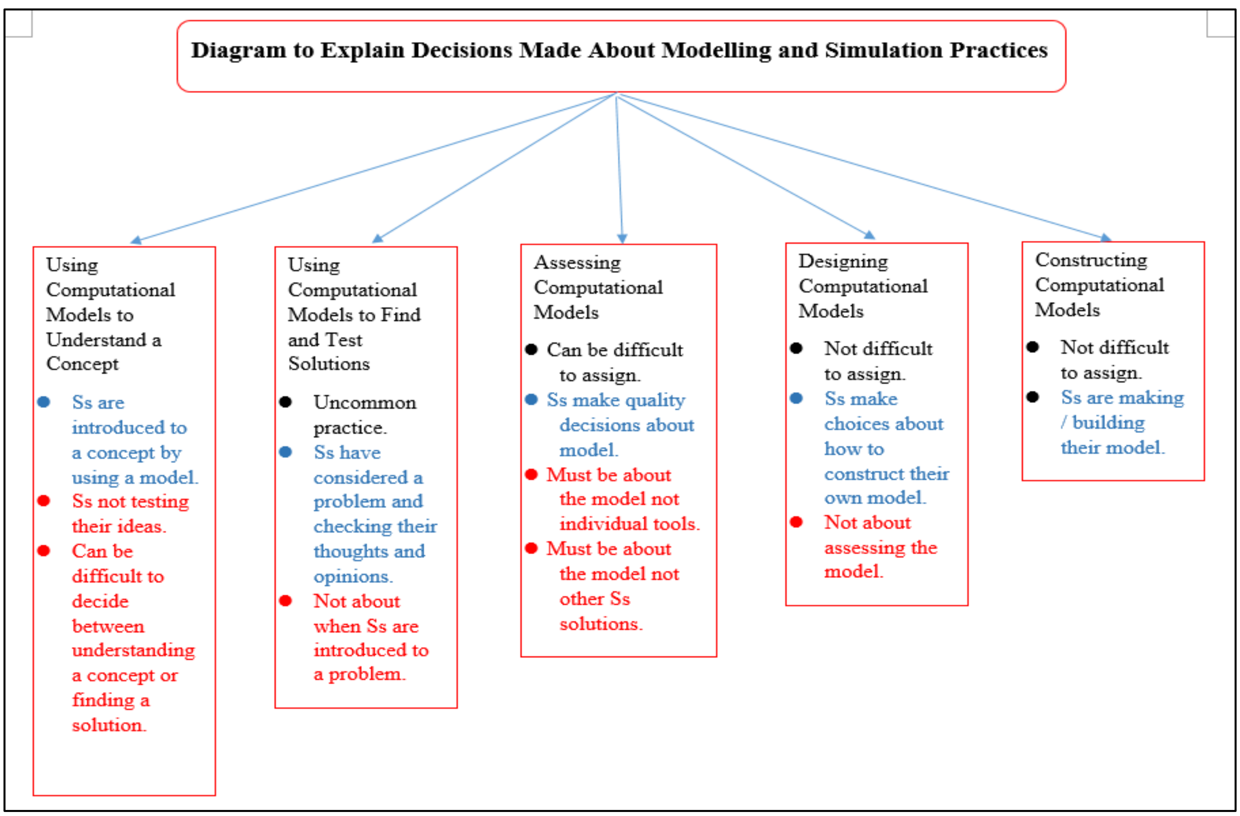


Figure 32. Diagram to explain decisions about assigning Modelling and Simulation Practices

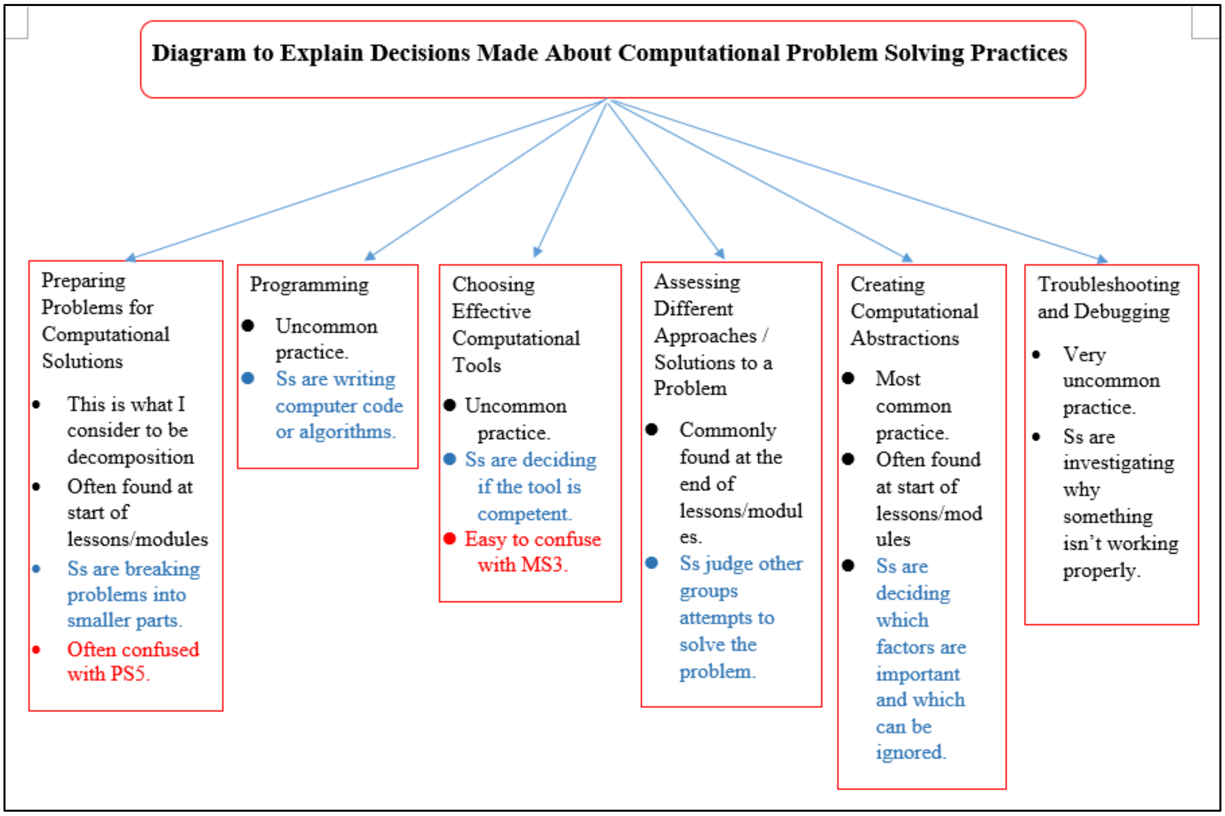
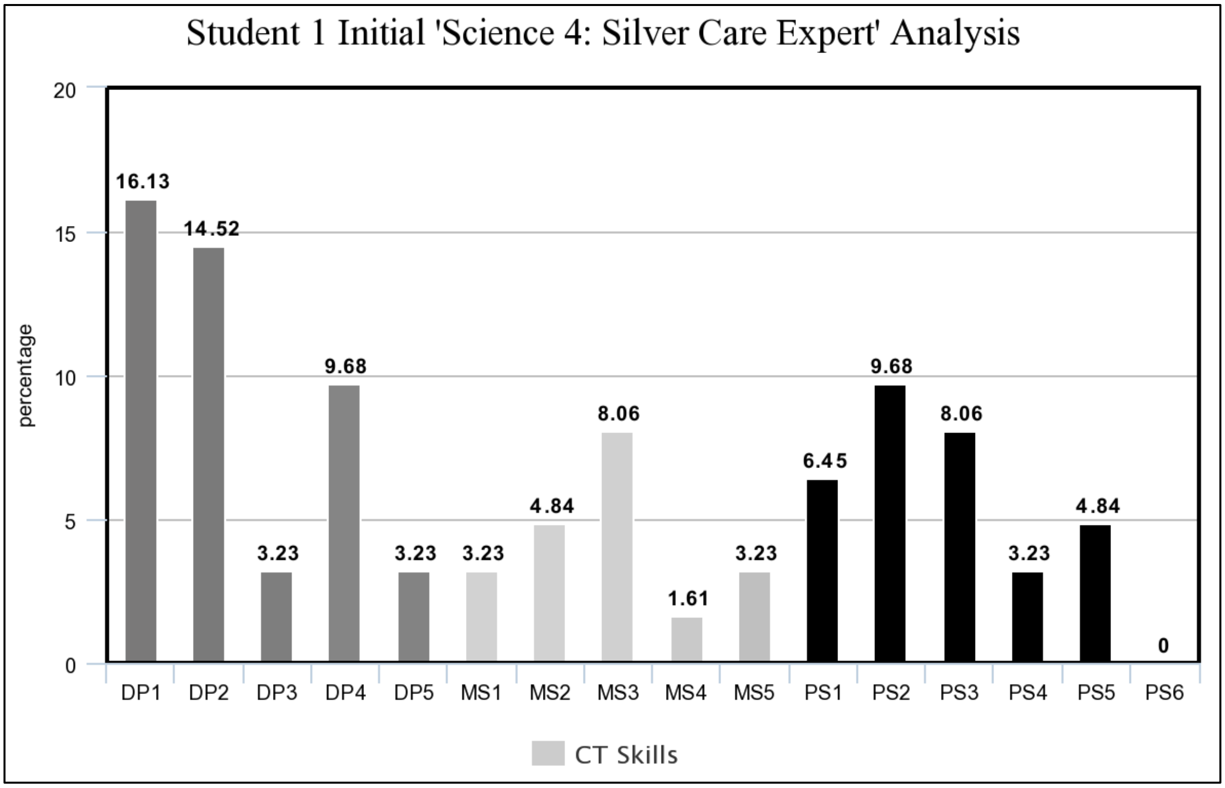


Figure 33. Diagram to explain decisions about assigning Computational Problem Solving Practices

The students were not given any further information apart from the diagrams so that there would be a baseline analysis with which compare their analysis after a discussion with the researcher. The following graphs (figure 34 and 35) show the results for both students' initial stage one analysis of 'Science 4: Silver Care Expert' module.

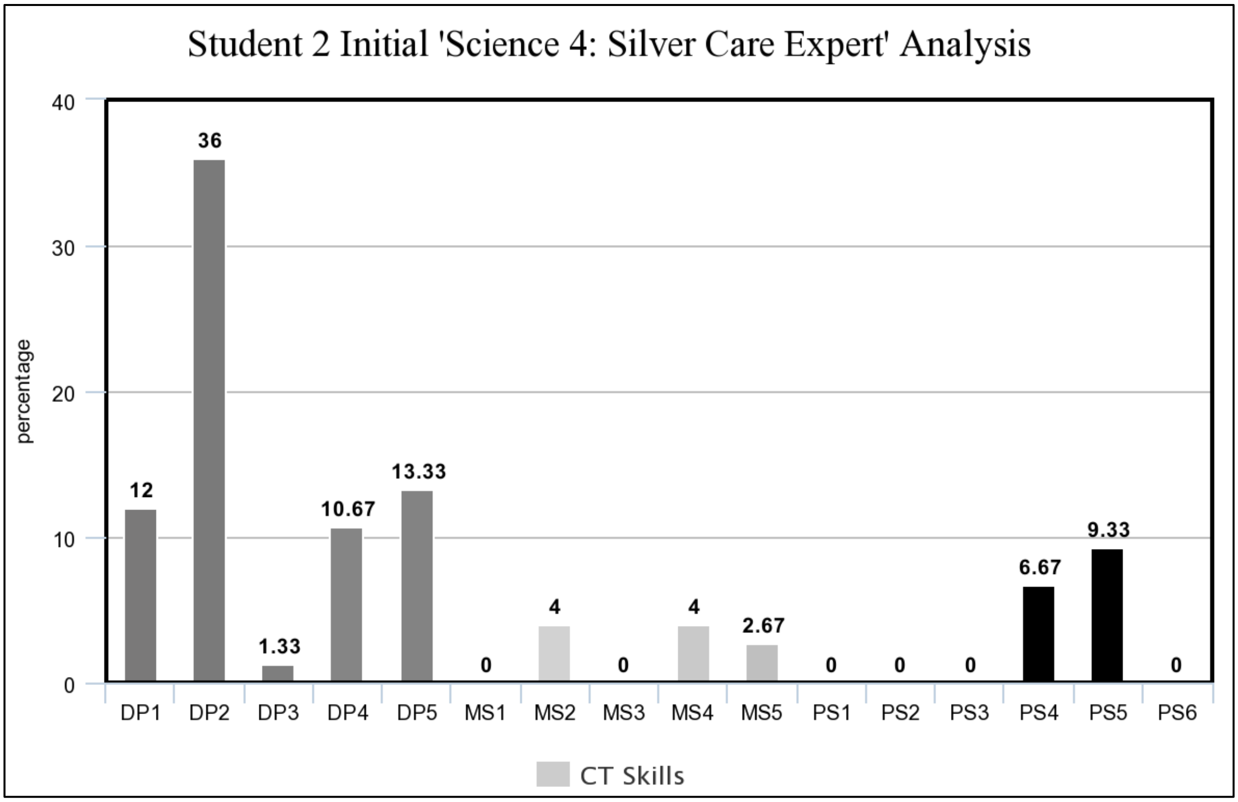


DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 34. Student 1's analysis of the 4^{th} Science STEAM program and it description

Student 1 found a total of 62 CT practices were found in this module. There were 29 (46.8%) Data Practices, 13 (21.0%) Modeling and Simulation Practices, and 20 (32.3%) Computational Problem Solving Practices. So student 1 found more Data Practices than Modeling and Simulation Practices.

Their most commonly found practice was DP1 (Collecting Data) 10 / 62 (16.1%). The practices were found in lessons 1 and 3 with 7 / 10 (70%) in lesson 1 and 3 / 10 (30%) in lesson 3. The second most found practice was DP2 (Creating Data) 9 / 62 (14.5%). They were found in all three lessons but more commonly in lessons 1 and 3. Student 1 found 4 / 9 (44.4%) instances in both lessons 1 and 3, with 1 / 9 (11.1%) found in lesson 2. There was only 1 practice that recorded zero instances, PS6 (Troubleshooting and Debugging).



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

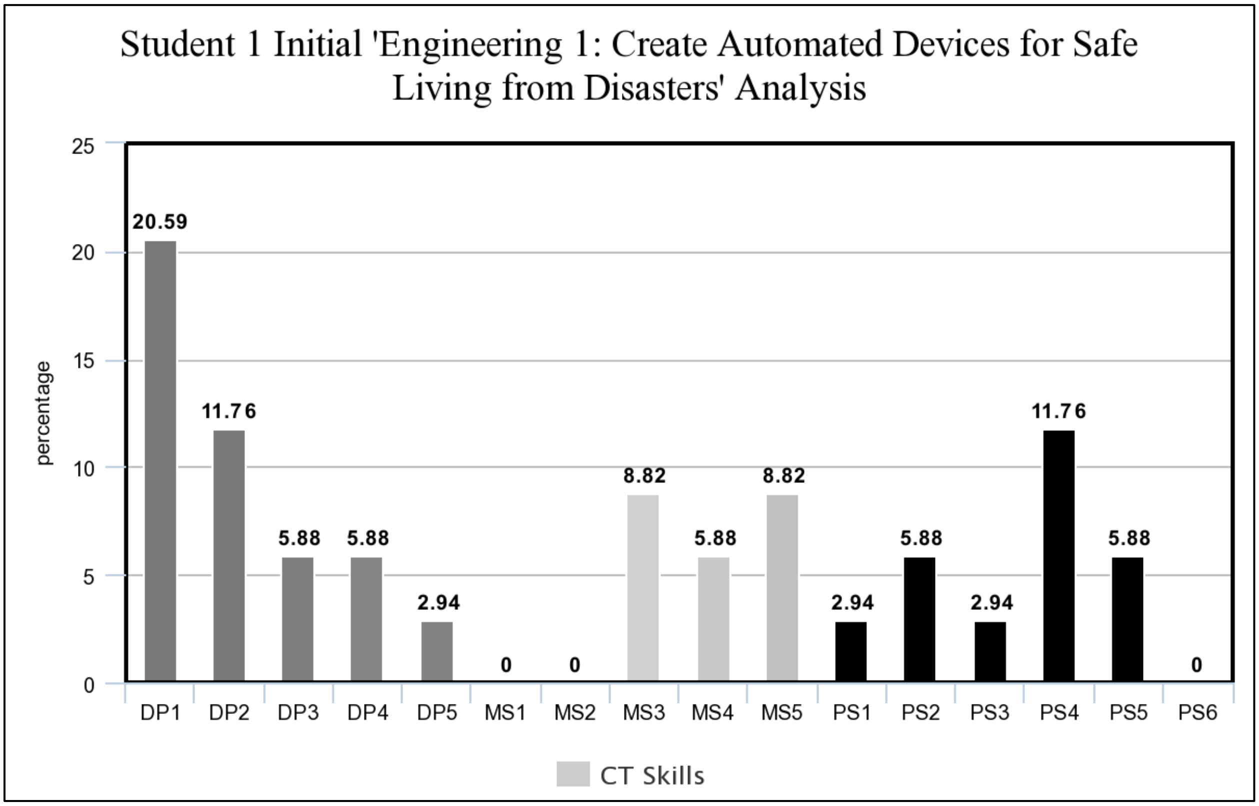
Figure 35. Student 2's analysis of the 4th Science STEAM program and it description

Student 2 found a total of 75 CT practices were found in this module. There were 55 (73.3%) Data Practices, 8 (10.7 %) Modeling and Simulation Practices, and 12 (16%) Computational Problem Solving Practices. So student 2 found more Data Practices, than Modeling and Simulation Practices, and Computational Problem Solving Practices.

Their most commonly found practice was DP2 (Creating Data) 27 / 75 (36%). The practices were found in all three lessons, but mostly in lessons 1 and 3. Lesson 1 had 10 / 27 (37.0%). Lesson 2 had 6 / 27 (22.2%). Lesson 3 had 11 / 27 (40.7%). The second most found practice was DP5 (Visualizing Data) 10 / 75 (13.3%). They were found in all three lessons but more commonly in lesson 2. Student 2 found 5 / 10 (50%) instances in lesson 2, with 3 / 10 (30%) found in lesson 1, and 2 / 10 (20%) found in lesson 3. There was 6 practices that recorded zero instances, MS1 (Using Computational Models to Understand a Concept), MS3 (Assessing Computational Models), PS1

(Preparing Problems for Computational Solutions), PS2 (Programming), PS3 (Choosing Effective Computational Tools), and PS6 (Troubleshooting and Debugging).

The following graphs (figure 36 and 37) show the results for both students' initial stage one analysis of 'Engineering 1: Create Automated Devices for Safe Living from Disasters' module.

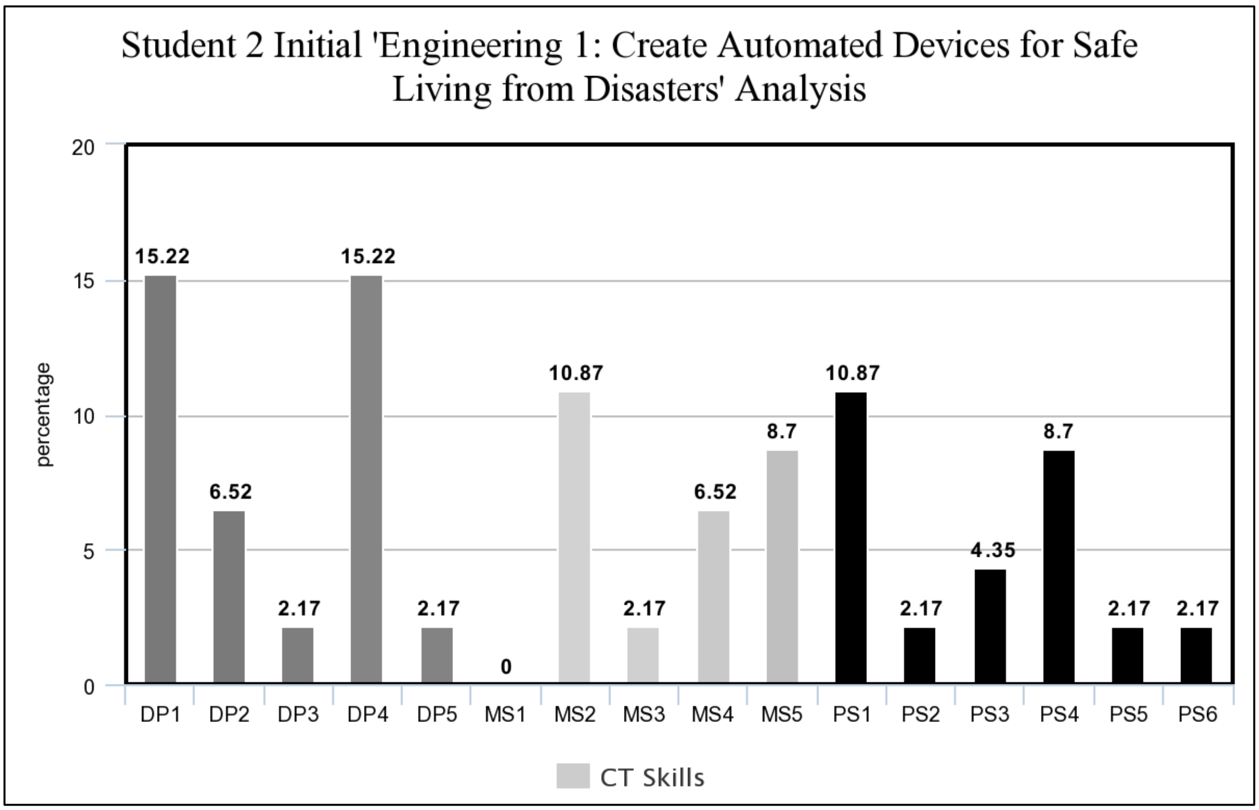


DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 36. Student 1's analysis of the 1st Engineering STEAM program and it description

Student 1 found a total of 34 CT practices were found in this module. There were 16 (47.1%) Data Practices, 8 (23.5%) Modeling and Simulation Practices, and 10 (29.4%) Computational Problem Solving Practices. So student 1 found more Data Practices than Modeling and Simulation Practices.

Their most commonly found practice was DP1 (Collecting Data) 7 / 34 (20.6 %). The practices were found in lessons 1, 2-3, and 4-7 with 1 / 7 (14.3%) in lesson 1 and 3 / 7 (42.9%) in lessons 2-3 and 4-7. The joint second most found practices were DP2 (Creating Data) and PS4 (Assessing Different Approaches / Solutions to a Problem) 4 / 34 (11.8%). The 4 instances of DP2 were found in lessons 1 and 2-3, while the 4 instances of PS4 were found in lessons 4-7 and 8. There were 3 practices that recorded zero instances, MS1 (using Computational Models to Understand a Concept), MS2 (Using Computational Models to Find and Test Solutions), and PS6 (Troubleshooting and Debugging).



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 37. Student 2's analysis of the 1st Engineering STEAM program and it description

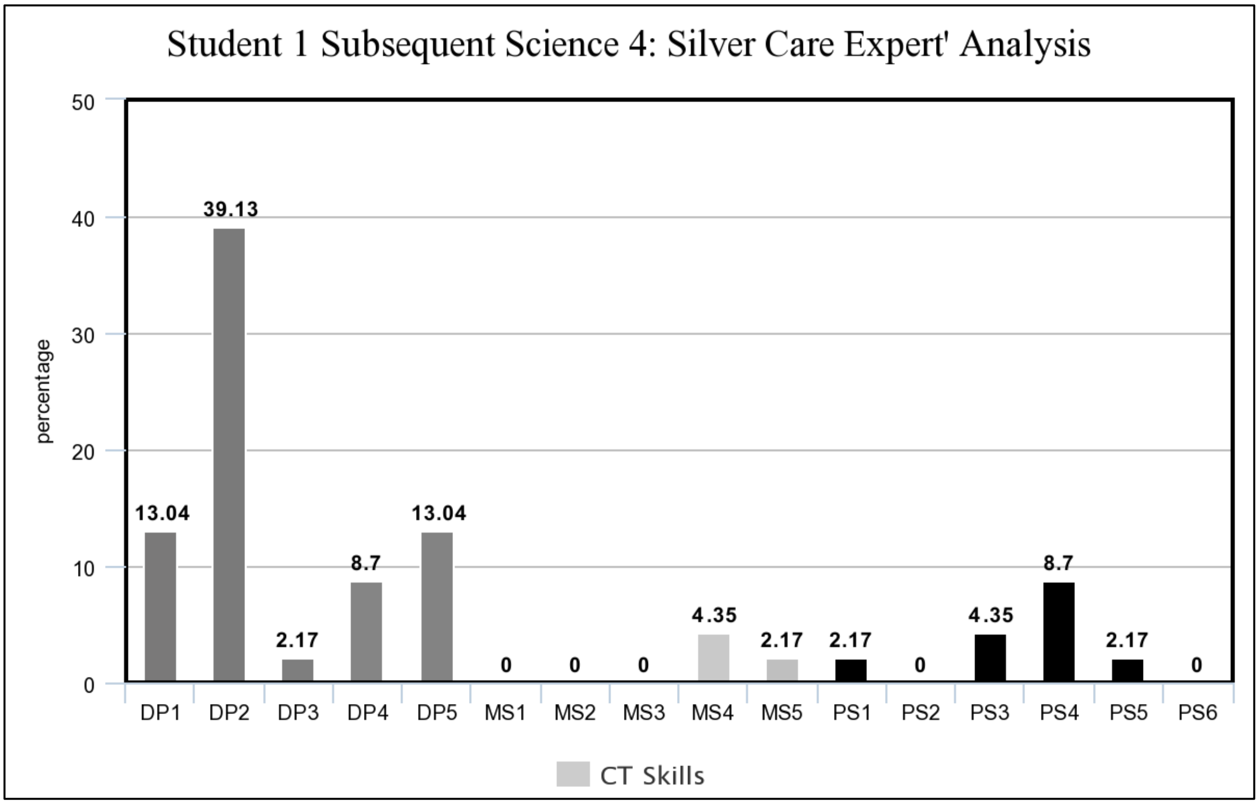
Student 2 found a total of 46 CT practices were found in this module. There were 19 (41.3%) Data Practices, 13 (28.3%) Modeling and Simulation Practices, and 14 (30.4%) Computational Problem Solving Practices. So student 1 found more Data Practices than Modeling and Simulation Practices, and Computational Problem Solving Practices.

Their joint most commonly found practice were DP1 (Collecting Data), and DP4 (Analyzing Data) with 7 / 46 (15.2 %). The instances of DP1 were found in lessons 1, 2-3, and 4-7 with 1 / 7 (14.3%) in lesson 1 and 3 / 7 (42.9%) in lessons 2-3 and 4-7. For DP4 the instances were also found in lessons 1, 2-3, and 4-7. There were 2 / 7 (28.6%) found in both lessons 1 and 2-3, and 3 / 7 (42.9%) found in lesson 4-7. There was only 1 practice that recorded zero instances, MS1 (using Computational Models to Understand a Concept).

After the students performed this analysis, the researcher met with the students (individually) to hear their thoughts and opinion on doing the analysis. The following are the students' 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.

The second stage started with a discussion between the researcher and students. The researcher presented the students with his opinions on the definitions of the CT practices and what some good examples (table 9) of how those practices could be used in the science education classroom. The purpose of this discussion was to reach a consensus between the researcher and students. The following graphs (figures 38 and 39) show how the students analyzed the 'Science 4: Silver Care Expert' module after the discussion with the researcher.

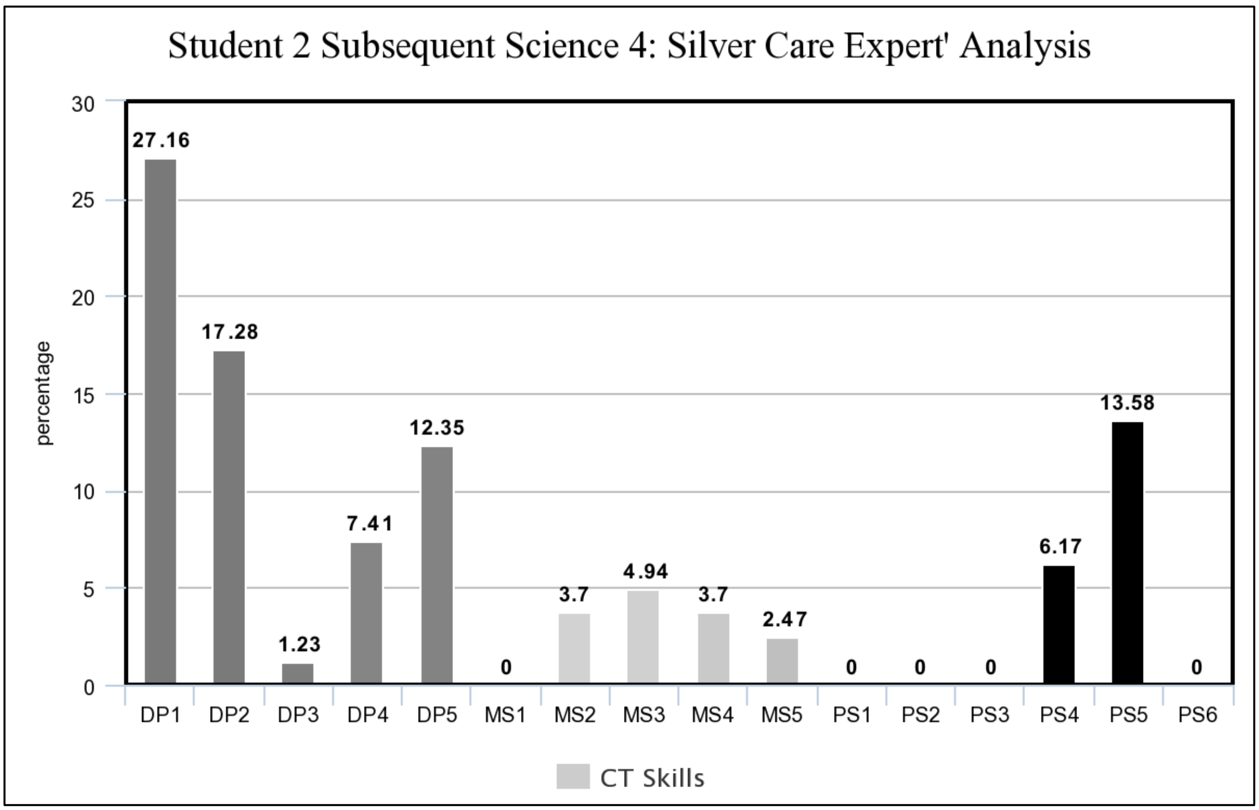


DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 38. Student 1's analysis of the 4th Science STEAM program and it description

Student 1 found a total of 46 CT practices were found in this module. There were 35 (76.1%) Data Practices, 3 (6.5%) Modeling and Simulation Practices, and 8 (17.4%) Computational Problem Solving Practices. So student 1 found more Data Practices than Modeling and Simulation Practices.

The most found practice was DP2 (Creating Data) 18 / 46 (39.1%). They were found in all three lessons but more commonly in lessons 1 and 3. Student 1 found 8 / 18 (44.4%) instances in lesson 1, with 3 / 18 (16.7%) found in lesson 2, and 7 / 18 (38.9%) found in lesson 3. The joint second most practices were DP1 (Collecting Data) and DP5 (Visualizing Data) with 6 / 46 (13.0%). There were 5 practices that recorded zero instances, MS1 (Using Computational Models to Understand a Concept), MS2 (Using Computational Models to Find and Test Solutions), MS3 (Assessing Computational Models), PS2 (Programming), and PS6 (Troubleshooting and Debugging).



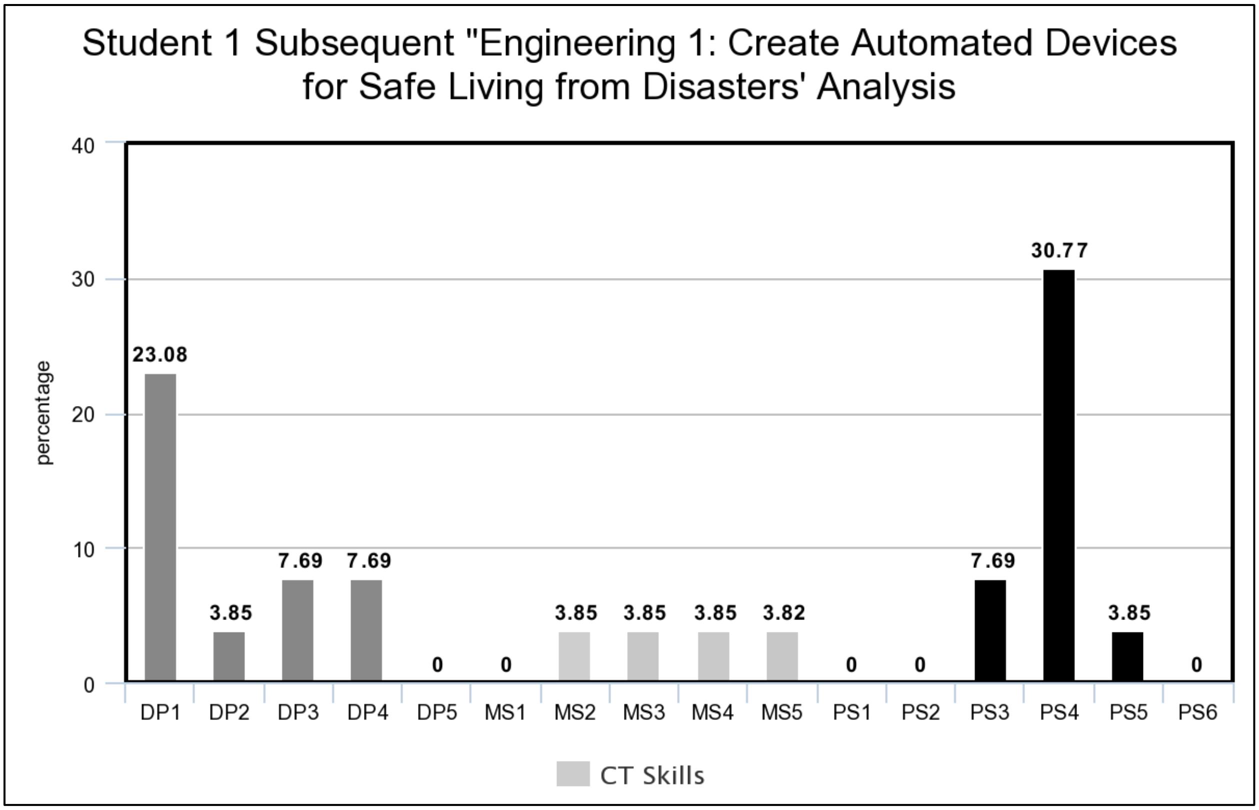
DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 39. Student 2's analysis of the 4th Science STEAM program and it description

Student 2 found a total of 81 CT practices were found in this module. There were 53 (65.4%) Data Practices, 12 (14.8%) Modeling and Simulation Practices, and 17 (21.0%) Computational Problem Solving Practices. So student 2 found more Data Practices than Modeling and Simulation Practices.

Their most commonly found practice was DP1 (Collecting Data) 22 / 81 (27.2%). The practices were found in all three of the lessons. They were found in all three lessons but most commonly in lesson 3. Student 2 found 7 / 22 (31.8%) instances in lesson 1, with 5 / 22 (22.7%) found in lesson 2, and 10 / 22 (45.5%) found in lesson 3. The second most found practice was DP2 (Creating Data) with 14 / 81 (17.3%). There were 5 practices that recorded zero instances, MS1 (Using Computational Models to Understand a Concept), PS1 (Preparing Problems for Computational Solutions), PS2 (Programming), PS3 (Choosing Effective Computational Tools), and PS6 (Troubleshooting and Debugging).

The following graphs (figures 40 and 41) show how the students analyzed the 'Engineering 1: Create Automated Devices for Safe Living from Disasters' module after the discussion with the researcher.

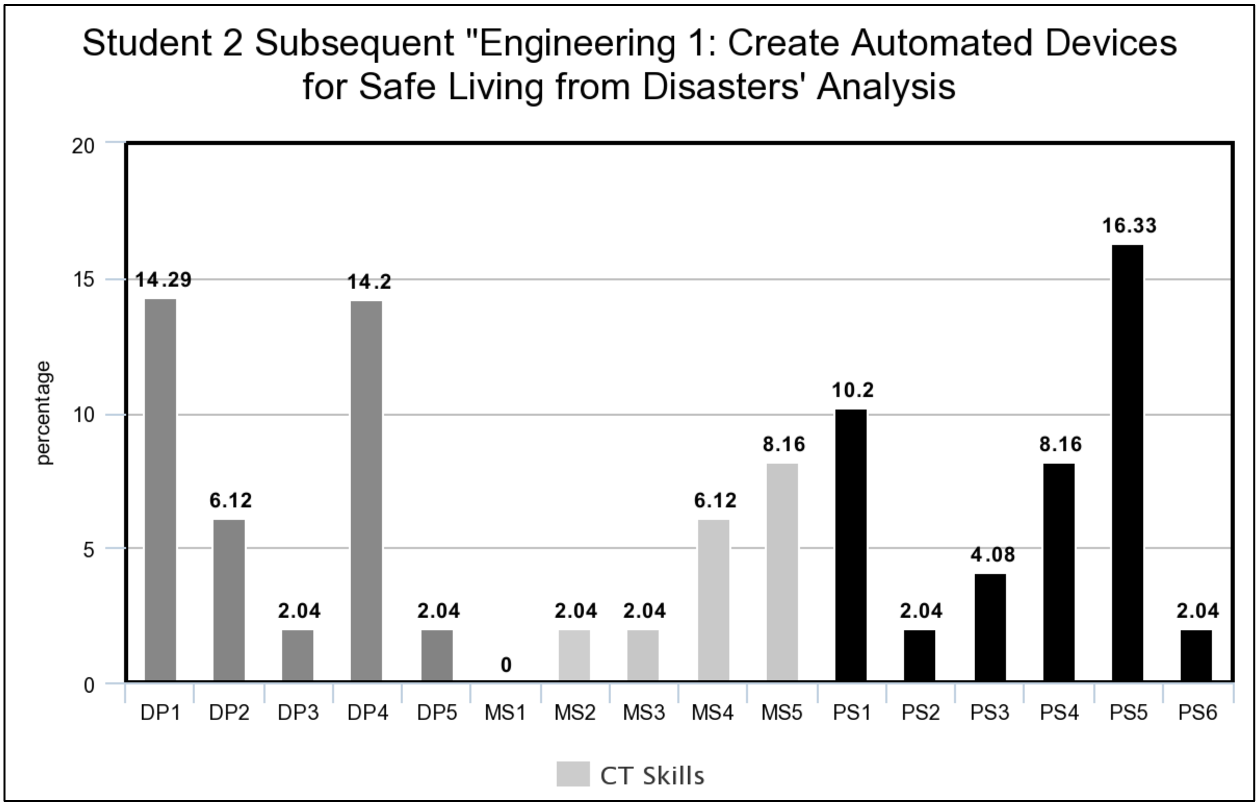


DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 40. Student 1's analysis of the 1st Engineering STEAM program and it description

Student 1 found a total of 26 CT practices were found in this module. There were 11 (42.3%) Data Practices, 4 (15.4%) Modeling and Simulation Practices, and 11 (42.3%) Computational Problem Solving Practices. So student 1 found more Data Practices and Computational Problem Solving Practices than Modeling and Simulation Practices.

The most found practice was PS4 (Assessing Different Approaches / Solution to a Problem) 8 / 26 (30.8%). They were found in all four lessons. Student 1 found 1 / 8 (12.5%) instances in lesson 1, with 2 / 8 (25%) found in lessons 2-3 and 4-7, and 3 / 8 (37.5%) found in lesson 8. The second most practice were DP1 (Collecting Data) with 6 / 26 (23.1%). There were 5 practices that recorded zero instances, DP5 (Visualizing Data), MS1 (Using Computational Models to Understand a Concept), PS1 (Preparing Problems for Computational Solutions), PS2 (Programming), and PS6 (Troubleshooting and Debugging).



DP = Data Practices, MS = Modelling and Simulation Practices, PS = Computational Problem Solving Practices

Figure 41. Student 2's analysis of the 1st Engineering STEAM program and it description

Student 2 found a total of 49 CT practices were found in this module. There were 19 (38.8%) Data Practices, 9 (18.4%) Modeling and Simulation Practices, and 21 (42.9%) Computational Problem Solving Practices. So student 2 found more Data Practices and Computational Problem Solving Practices than Modeling and Simulation Practices.

The most found practice was PS5 (Creating Computational Abstractions) 8 / 49 (16.3%). They were found in all four lessons. Student 1 found 2 / 8 (25%) instances in lesson 1, with 3 / 8 (37.5%) found in lesson 2-3, with 2 / 8 (25%) in lesson 4-7, and 1 / 8 (12.5%) found in lesson 8. The joint second most practices were DP1 (Collecting Data) and DP4 (Analyzing Data) with 7 / 49 (14.3%). There was only 1 practice that recorded zero instances, MS1 (Using Computational Models to Understand a Concept).

4.4.2 Analysis of Results 4

After the second analysis by the students the researcher met with them again to discuss their thoughts and opinions. During these discussions the researcher asked the students to explain why their analysis changed from the first analysis to the second analysis.

Student 1 considered their analysis to be much "stricter" the second time. They thought that the activities in the modules should fit exactly with the definitions outlined by the researcher in table 9. This student also expressed how with the first analysis they only really understood the meaning of the Data Practices (DP) and so thought that they had over-subscribed the instances of the DP practices.

The researcher and student 1 had an interesting discussion about a difference of opinion between how the researcher's analysis had more instances of PS5 (Creating Computational Abstractions) than the student's analysis. To try and understand the student's thought process the researcher showed the student an activity from a module that the student had not yet seen and asked the student to say what CT practice they thought it was and why. The activity (figure 9) involved the students considering the events of a movie about solar flares causing communication failures on Earth. The student described this activity as DP4 (analyzing data) as they felt the events of the movie could be considered data and so the students would be analyzing that data to find the cause of the communication failures. The researcher considers this activity to be PS5 (Creating Computational Abstractions). After the researcher explained their position the researcher and student 1 reached a consensus that the ideas about the activity were similar, but emphasizing different aspects. Student 1 is emphasizing the analysis of the data (the movie), while the researcher emphasized the decisions about what factors were important in causing the communication failures.

Student 2 was very interested to hear about the researcher's opinions on PS1 and PS5. During the first analysis they had not held the viewpoint that PS1 is the practice of decomposition and that PS5 is the practice of abstraction. Being familiar with science education terms they knew of both decomposition and abstraction but not associated them with the CT practices. Interestingly, this led to an increase for the number of instances of PS5, but actually saw a decrease in the number of instances of PS1. This lead to a discussion between the student and researcher about the difficulties and confuse that can often surround decomposition and abstraction. There was agreement on the fact that the 'book' definition of the two practices is easy to distinguish, but it in practice it can be difficult to tell them apart.

Based on the discussions between the researcher and students, the researcher has produce a guideline book that could be used by pre-service and in-service teachers as part of a professional development program to learn about and increase their knowledge and understanding of CT. The guideline book can be found in the appendix. The guideline goes through each of the sixteen CT practices found in the CT_AT and gives a definition, and how CT has changed this practice. There will then be two examples of this practice in action. The first will be an example of an activity where the students are strongly exposed to the practice. The second example will be of an activity that could be confused for the practice, but is reality a different CT practice. Finally, there will be some information about where the practice is commonly found in modules and lessons, and thoughts and opinion that the researcher reached through their study of CT.

Chapter 5: Conclusion and Implication

The researcher set out to answer three research questions with this paper. The research questions were as follows:

1. Based on learnt knowledge, what kinds of CT practices can be found in STEAM programs and what description of CT in STEAM can be illustrated?
2. Through continued professional development, what additional or extended CT practices can be suggested to revitalize STEAM programs on the basis of the descriptions made above?
3. After coming towards the end of self-study journey what difficulties are encountered when developing a new STEAM module from the viewpoint of exposing the students to CT practices

4. From the experience gathered during the self-study how can the researcher develop a professional development program to aid pre-service and in-service teachers' in their own journey to study computational thinking?

In seeking an answer for the first research question the developed CT_AT was used to analyze five science focus STEAM programs and five engineering focused programs. The patterns of CT practices were interpreted to make the following conclusions. When looking at the individual modules there is often a distinct difference in the distribution of the instances of the CT practices found in the major categories practices of Data Practices (DP1 to DP5), Modeling and Simulation Practices (MS1 to MS5), and Computational Problem Solving Practices (PS1 to PS6). An example of this uneven distribution would be engineering 5 where 66.7% of the CT practices were PS (computational problem solving practices). An example from the science focused modules would be science 3 which was 57.1% PS practices. However, when combining the all the science modules together and the engineering modules together the uneven distribution disappears and the CT skills are evenly found in the three major categories of DP, MS, and PS. This result shows that the discipline (science or engineering) doesn't determine what CT practices will be found. This conform with Wing (2006; 2008) who stated that CT can be applied to any subject or even people's everyday lives. CT practices of STEAM programs are not dependent on the discipline but rather the activities the course creator put into the program. Further research is needed to see if the found even distribute is also present in a variety of other disciplines.

We expect students to learn science concepts and its core competencies through STEAM programs (Park, & Park, 2018a) to be creative problem solvers and CT practices are found in STEAM programs even though they may be weakly exposed. CT practices are not new but implicitly embedded in STEAM programs. It is necessary for CT to be exposed explicitly by the teachers in developing or teaching STEAM programs in the classroom. The CT analyzing tool developed and employed in this study can provide a framework for teachers to use.

The second research question was to see if additional or modified activities could be suggested to enhance weakly exposed or missing CT practices. Using the data obtained for research question 1 the researcher developed some activities so that students could have more chances to experience various types of CT practices. The validity of the added or modified CT practices has been constructed through discussions to form a consensus but there is still room for further discussion. Moving forward the validity can be generalized for other disciplines in the classroom. Nevertheless, the fact that weakly exposed or missing practices were able to be improved shows that teachers and course creators can follow the same approach to enhance their own content. This will allow for students to experience a course rich in CT practices providing them chances to acquire the skills required to be the creative problem solvers that society needs in the 21st century.

The third research question was to see if a course could be created from scratch with the view of exposing the students to CT practices. The researcher developed the idea on the basis of their educational background. Briefly, the students will look at why humans may need to find another place to live, where that place could be and what would be needed for a colony to be successful. Once the course was created it was analyzed with the same method used to analyze the existing STEAM programs. The results show a course that offers students the chance to experience a full range of the CT practices with only the MS3 practice missing. It is the researcher's belief that with additional developed this missing practice could be included and other weakly exposed practices also enhanced. Further research is needed to solidify the validity of the developed course but its creation shows that it is possible to create a course from scratch with the view of including CT practices. This proves that going forward teachers and course creators can also develop course with the purpose of exposing students to CT practices. The CT practices that students need to be effective members of a 21st century society.

The fourth research question was to see if from the experience gathered during the self-study how can the researcher develop a professional development program (PDP) to aid pre-service and in-service teachers' in their own journey to study computational thinking? To answer this question the researcher asked two students with backgrounds in science and science education to use the CT_AT to analyze two STEAM modules. An informal and conversational method was used as it was thought that the cyclical nature of PAR would best allow for the researcher and students to reach consensus about how best to develop a professional development program. The researcher and students agreed on many aspects of the analysis, but there were also many differences of opinion. Through discussions the researcher and students were able to reach a consensus on some changes that could improve the CT_AT to make it more useful in a PDP setting.

The first change that was suggested was to change the name of the PS2 practice from ‘programming’ to ‘programming and algorithms’. The students both thought that this name would be more applicable to science education classrooms as “the use of programming is rare in science, but algorithms are used all the time”.

The second change that was suggested by one of the students was to include the word ‘decomposition’ in the name of PS1 (Preparing Problems for a Computational Solution). They argued that ‘decomposition’ is a well-known word to teachers, especially in science education, and so it would make it clearer what the researcher believes the practice involves. The researcher therefore changed the name of PS1 to ‘Decomposing Problems to Allow for a Computational Solution’.

A future study that involved more pre-service and in-service teachers would allow for more critical episodes for the researcher to move closer to a tool that can be used as part of a PDP. It would very useful to discuss the tool with teachers from different levels, elementary, middle, and high school, to make an analyzing tool that can be used at all levels, and if that is not possible to produce ‘fine-tuned’ tools for the different levels. It would also be beneficial to discuss the tool with teacher from the various STEAM disciplines to produce tools for those various disciplines.

The CT analyzing tool (CT_AT) with its operating definitions and its examples in science education can provide the instructions of how to include CT practices into the classroom by STEAM programs. The researcher has released that there is a gap between theory and practice from new policy and new curriculum, most educators and teachers have been struggled to capture the way of how to implement ‘computational thinking’ practice out of the 8 envisioned in NGSS (2013) and ‘computer use’ in Korean revised science curriculum (2015). To bridge the theory and practice in ‘computational thinking’ competency envisioned in the 21st century, this study can make step forward to make STEAM programs to be revitalized in Technology and Engineering more than before. The CT analyzing tool frame in this study should be developed in detail with more forth coming research and its validity should be further established.

In conducting this self-study the researcher went through a process of personal growth and development. When the researcher first met with his supervisor and started to have conversations with her about CT, the researcher’s knowledge level was limited. Many of the concepts of CT, such as, the different data practices were well understood. Others, for instance, decomposition and abstraction were known ideas on a surface-level but there was no deep knowledge of how these concepts present themselves in classroom settings and how teachers go about guiding their students to master them. By going through the literature review and putting ideas into practice by analyzing STEAM programs, suggesting enhancements to revitalize CT practice in those STEAM programs, and developing his own module with an emphasis on CT, the researcher’s knowledge and perception grew and changed, which can imply systematic professional development. CT now has a place in curriculums around the globe and teachers need their own professional development programs to grow and change their perceptions of CT. It is the researcher’s hope that teachers will be able to read this dissertation and use the CT_AT to follow the researcher’s journey of self-study from CT novice to CT expert. To aid teachers in their study of CT the researcher made a guideline book (appendix) that could be used by teachers to increase their knowledge of CT and how to apply it is their classroom.

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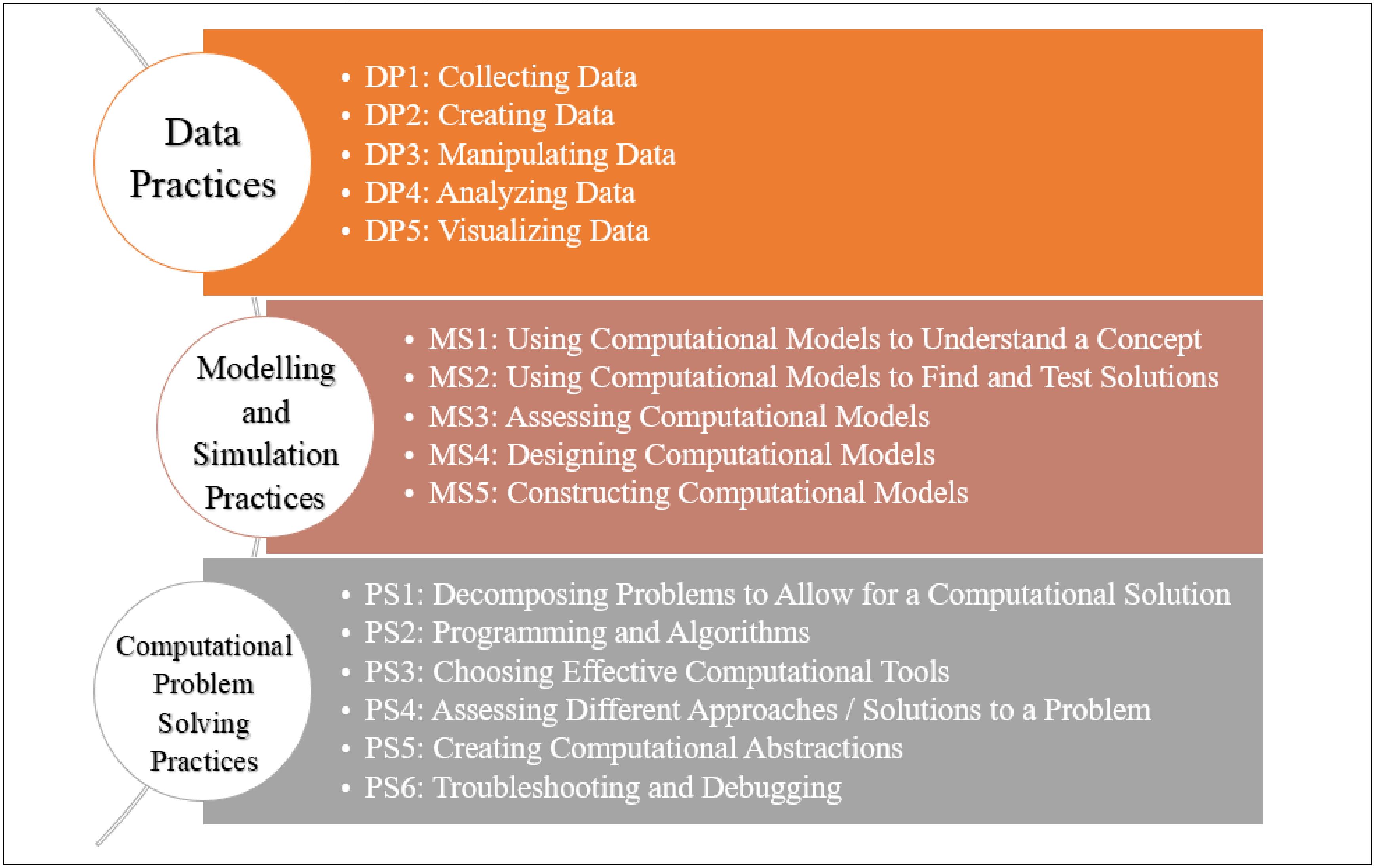
Appendix

A: Computational Thinking Analyzing Tool (CT_AT)



B: Developed STEAM Module

Where Can We Go and How Can We Live There if the Earth Becomes Uninhabitable?

Module Introduction

Purpose in Developing this Module

The overall objective of developing this module was to design a STEAM module systematically from the bottom up from the viewpoint of exposing the students to computational thinking (CT) practices. CT is an established term in computer science classes but it is not well developed for STEAM classes. This module was therefore designed with the purpose of integrating a wide range of CT practices to give students the experiences of problem solving, problem decomposing, and abstraction that is promoted by CT.

Story of the Module

The overall story of the module is that the human race is facing the danger of the Earth becoming uninhabitable due to climate change. While acknowledging the need to fight climate change and work together to help save the Earth, the module asks the students to consider the idea that we need to leave the Earth and find a new place to live. The students will consider what places are suitable for human settlement and what humans require to live in those places.

Story of Lesson 1

Lesson 1 suggests some possible events that could spell the end of the human race. The lesson then focuses in on the issue of climate change. The students are presented with data about the average temperature of the Earth from 1880 to 2020. The students will plot the data point and deduce for themselves how the temperature of the Earth is changing over time. They then perform an experiment to see how the rising sea level, caused by the rising temperature, will affect humans.

Story of Lesson 2

Lesson 2 is the students investigating different options for places in the solar system that humans could colonise. The students will gather data about how suitable the places are for human colonization. The second activity of lesson 2 is the students doing an experiment to observe how plants produce oxygen through the process of photosynthesis.

Story of Lesson 3

Lesson 3 starts with the students studying Newton's third law of motion and how it explains what is happening when a rocket is launched. The students then look at how rockets are launched with multiple stages to reduce cost and construct their own model of a multi-stage rocket using balloons.

Story of Lesson 4

Lesson 4 begins with the students using their learned knowledge to design their own Martian colony. The groups consider the insights from the previous lessons to decide what buildings and structure they need in their colony to satisfy the needs of the colonists. The students then build their own rover and program it to follow a predetermined course.

Websites Used For Inspiration

The following websites were used as inspiration in this module.

- https://www.jpl.nasa.gov/edu/teach/activity/graphing-global-temperature-trends/
  Used for Lesson 1 Activity 1.
- https://www.teachengineering.org/activities/view/cub_air_lesson07_activity2
  Used for Lesson 1 Activity 2.
- https://www.space.com/28355-living-on-other-planets.html
  Used for Lesson 2 Activity 1.
- https://www.wikihow.com/Show-Oxygen-Is-a-By-Product-of-Photosynthesis
  Used for Lesson 2 Activity 2.
- https://www.sciencebuddies.org/teacher-resources/lesson-plans/two-stage-balloon-rocket#lesson
  Used for Lesson 3 Activity 1.
- https://www.vivifystem.com/blog/2019/4/30/design-a-colony-on-mars-stem-project
  Used for Lesson 4 Activity 1.
- https://marsed.asu.edu/lesson_plans/marsbound
  Used for Lesson 4 Activity 1.

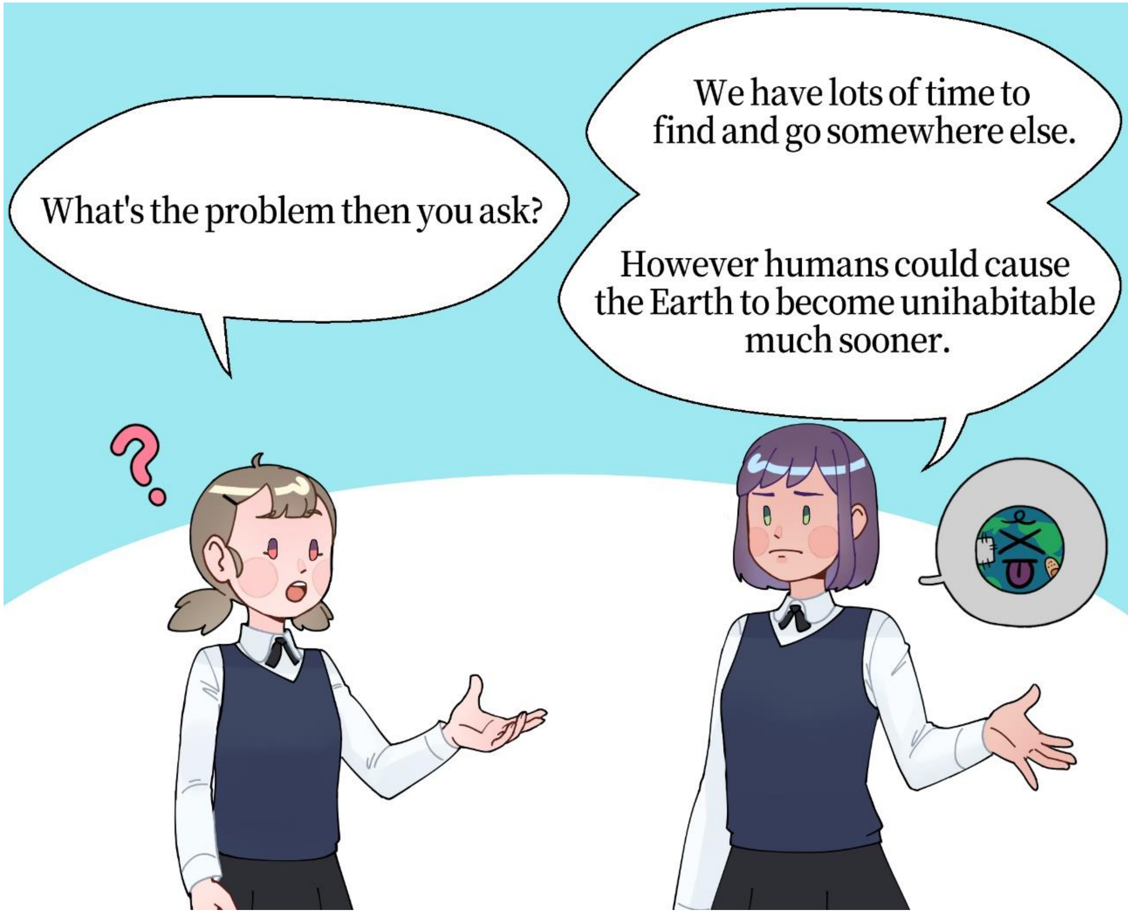
Opening Thoughts

We know that the Earth is doomed eventually!!!

The Sun is an ordinary G-type star. The Sun's lifespan started about 4.5 billion years ago, which means it has about 5 billion years of life left. However the Sun is getting brighter and brighter, which means more and more solar energy reaching Earth, causing the temperature to go up. In about 1 to 3 billion years the Sun will have heated the Earth so much that the oceans will boil and all the water will be lost to space. Then life on Earth will be impossible.

[4]

[4] Image taken from https://www.smithsonianmag.com/science-nature/the-end-of-the-world-might-just-look-like-this-14006468/



Think About It!!!

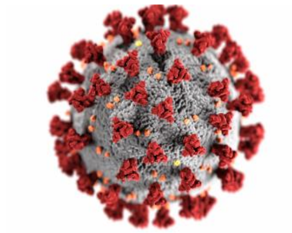
With your partner talk about possible ways that humans might make the Earth uninhabitable. Compare your list with the other group and discuss which you think is the most likely end of the Earth.

Lesson 1: Why We Might Need to Leave?

Lesson 1 Opening Thoughts: What Disastrous Event Might Happen?

There are many possible ways that all human live on Earth might be in danger.


[5]
Nuclear War


[6]
Global Pandemic


[7]
Meteor Strike

In this lesson we are going to look at a different event that might put humans in danger, climate change.

Think About It!!!

With your partner/group discuss what the term climate change means to you.

[5] Image from https://www.ready.gov/ko/node/5152
[6] Image from https://www.osce.org/representative-on-freedom-of-media/448849
[7] Image from https://www.forbes.com/sites/jonathanocallaghan/2020/02/15/no-the-asteroid-is-not-going-to-hit-earth/#4fd9ce2b284a

Activity 1: The Warming Earth?

One of the most scientifically accepted ways that humans might make the Earth uninhabitable is by the rise in global temperatures. In this activity we are going to look at how the global temperature is changing both short-term and long-term.[8]

As we are going to look at the temperature over such a long period of time each group is going to plot a 20-year period and then we will combine all the groups work to see the complete long-term pattern.

Think About It!!!

As we are going to combine all the graphs together we need to all use the same style and scale. In your group decide which of ‘temperature’ and ‘year’ should be the x-axis and which should be the y-axis. You should also decide the scale of each axis.

Think About It!!!

Now that the class has decided on the axis and scale what do you predict will be the result? Write down what your group thinks the graph will look like and why? Will there be an increase or decrease in temperature, or will it stay almost the same?

[8] Activity idea from https://www.jpl.nasa.gov/edu/teach/activity/graphing-global-temperature-trends/

☞ Now we need to collect the data. You can go to the NOAA (National Oceanic and Atmospheric Administration) website (https://www.ncdc.noaa.gov/cag/global/time-series) to find the data for your group's time period. The data gives the temperature anomalies (difference) with respect the 20th century average. A positive number means the temperature was warmer than the average. A negative number means the temperature was colder than the average. Add you collected data to your graph.

Think About It!!!

What does the data show?

Do you see an increase or decrease in the temperature?

Does this match what you thought would happen?

Do you think that when we look at the complete graph it will look the same as your group's graph?

Think About It!!!

☞ All the groups will now tape their graph on the whiteboard in the correct order.

What does the data show?

Do you see an increase or decrease in the temperature?

Does this match what you thought would happen?

Has the trend always been the same? When does it change?

Can you think of any historical reasons why the trend might have changed around this time?

What do you think is going to happen in the future?

Activity 2: What Does a Raising Temperature Mean for the Earth?

As the temperature of the Earth rises more and more of the ice at the poles will melt. This means that the sea level will rise. Most estimates says that the water will rise by at least 2 metres by the end of the century, which means about 200 million people will find their homes underwater. If all the ice melts then the water will rise by about 70 metres.[9]

☞ We are going to make a model of the greenhouse effect. Many people around the world know what the greenhouse effect is, and almost everybody thinks it is a very bad thing. But the greenhouse effect is natural and in fact we need it. Without the greenhouse effect the average temperature of the Earth would be -18ºC and no live would be possible. However because of the greenhouse effect our Earth has a pleasant average temperature of 14°C. The problem therefore is that we are increasing the effect of the greenhouse too much.

☞ Using the modelling clay make a model of a coastline or island in the aluminium tray. Try to make some mountainous areas and lowland areas. You should also make an area representing a city or group of houses on the lowland.

☞ Pour in the water that the teacher gives you. Make sure you don’t pour too much in!!

☞ Put the block of ice that the teacher gives you on the tallest part of your clay model. Then cover the model with a layer of plastic wrap. The plastic wrap is modelling the greenhouse gases in the atmosphere. Put your model in a warm (but not too hot) place.

[9] Activity idea adapted from https://www.teachengineering.org/activities/view/cub_air_lesson07_activity2

Think About It!!!

What do you think is going to happen to the model?

The teacher also made a model but didn't cover it with plastic wrap. Do you think the ice in the teacher's model will melt faster or slower than in yours?

☞ Measure the amount of water in the models regularly. Whose ice melts faster?

Lesson 1 Closing Thoughts: Self-Evaluation

What is being evaluated?	Rating Scale			
	Excellent	Good	Average	Poor
What issue(s) is investigated in this lesson: ______________________________				
What is your understanding of the issue(s) presented in this lesson?				
What is your scientific understanding of the issue(s)?				
What is your understanding of what will happen in the future with regards to the issue(s) of this lesson?				

Lesson 2: Where Should We Go if the Earth Becomes Uninhabitable?

Lesson 2 Opening Thoughts: How Can We Make Sure That the Human Race Survives?

In lesson 1 we saw that the data shows that the Earth is warming up, which means the sea levels will rise. We should be fighting climate change but many different things could happen and we need to be prepared. Could humans find another place to live, so that we have a bigger chance of survive a disastrous event?

Activity 1: What would it be Like to Live on Another Planet?

In the lesson 1 we saw that the Earth's temperature is rising and that the sea-level with go up as the ice melts. Humans are trying to save the Earth by such actions as recycle, renewable energy, and planting trees. But what if we are not successful? We will need to find somewhere else to go.[10]


[10]

[10] https://www.space.com/28355-living-on-other-planets.html

Think About It!!!

What are some of the places we could go?
What are some of the things that humans need to survive? (e.g. temperature range)

Make a list of places that you think humans could live if the Earth becomes uninhabitable.

The teacher will give each member of the group a place to research. You should use the internet to collect information about your place. Try to find information about how well your place meets the needs of humans that you thought about before.[11]

My Place to Research:____________________

Think About It!!!

Come together as a group and introduce your place to the other members. As a group compare all the place and decide which place would be best for humans to try to live on. A good way to compare the places would be to make a list of each place's pros and cons.

[11] Teacher can find suggestions and starting information at https://www.space.com/28355-living-on-other-planets.html

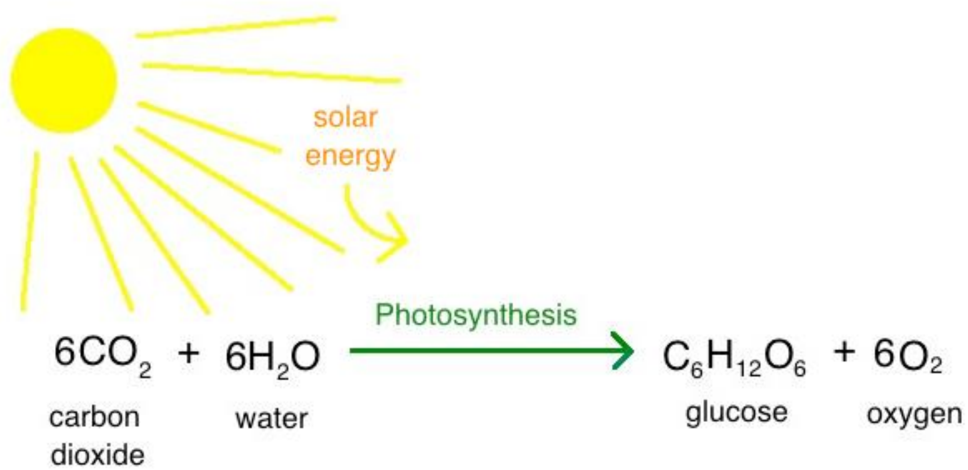
Activity 2: How Can We Breathe?

☞ One of the things that humans definitely need to live is oxygen. Earth is the only place in the solar system that has an atmosphere that we can breathe. But maybe it is possible to make our own oxygen.

☞ We are going to do an experiment to make our own oxygen using photosynthesis.[12]

Think About It!!!

Photosynthesis is the process of plants using sunlight, carbon dioxide, and water to make the energy (glucose) they need to survive. Luckily for us photosynthesis also produces oxygen.

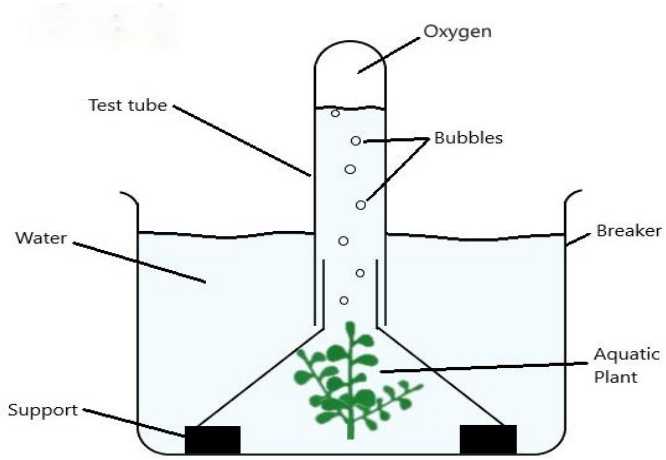


[13]

[12] Activity idea from https://www.wikihow.com/Show-Oxygen-Is-a-By-Product-of-Photosynthesis

[13] Image taken from https://www.khanacademy.org/science/high-school-biology/hs-energy-and-transport/hs-photosynthesis/a/hs-photosynthesis-review

☞ We are going to do an experiment to show how plants can be used to generate the oxygen we will need for our colony. The equipment is setup as follows:



Tips for a successful experiment

» You will need to mix in some baking soda to the water to make a sodium bicarbonate solution. This will provide the plant with the carbon dioxide it needs for photosynthesis.

» When turning over the test tube make sure it full of water. You will need to put your thumb over the top to stop the water falling out.

» Put some supports under the funnel to allow the sodium bicarbonate solution to circulate properly around the plant.

Think About It!!!

How do we know that oxygen was produced? We know that things burn easily in the presence of oxygen. So if a smoldering match bursts into flames we know we have oxygen.

☞ Slowly take the test tube off the funnel and while it is still in the water put your thumb over the end so the water and oxygen don't escape. With your thumb still over the end turn it the right way up so that the oxygen is at the top.

☞ Your partner should light a match and then quickly blow it out, so it is still smoldering. Take your thumb off the test tube and have your partner put the smoldering match in the test tube (be careful not to touch the water).

Think About It!!!

What happened to the match and what does that mean we can say about photosynthesis?

Lesson 2 Closing Thoughts: Self-Evaluation

What is being evaluated?	Rating Scale			
	Excellent	Good	Average	Poor
What issue(s) is investigated in this lesson: ______________________________				
What is your understanding of the issue(s) presented in this lesson?				
What is your scientific understanding of the issue(s)?				
How well did the experiment help with your understanding of the issue(s) of this lesson?				

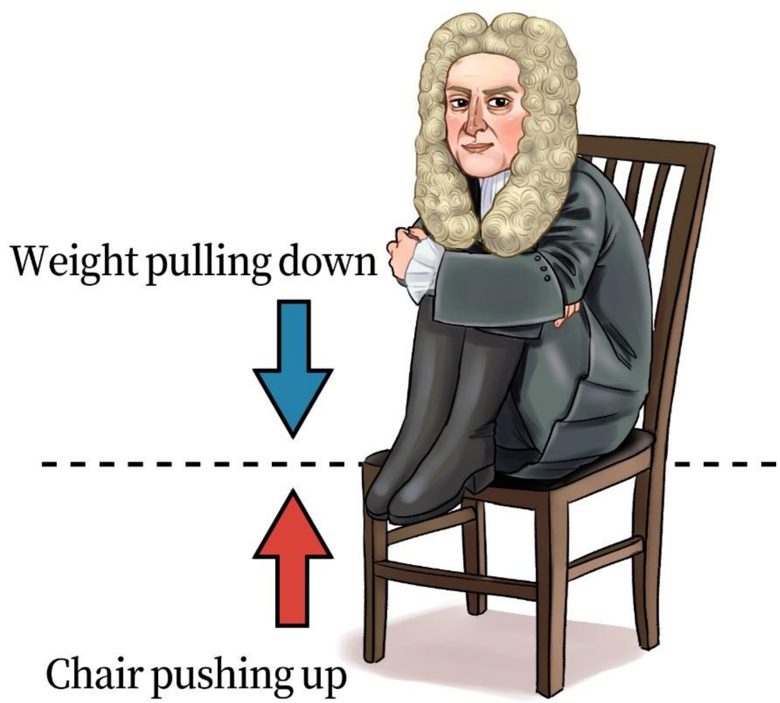
Lesson 3: Can You Make a Rocket to Get Into Space?

Lesson 3 Opening Thoughts: Newton's Third Law of Motion

Newton's third law is:

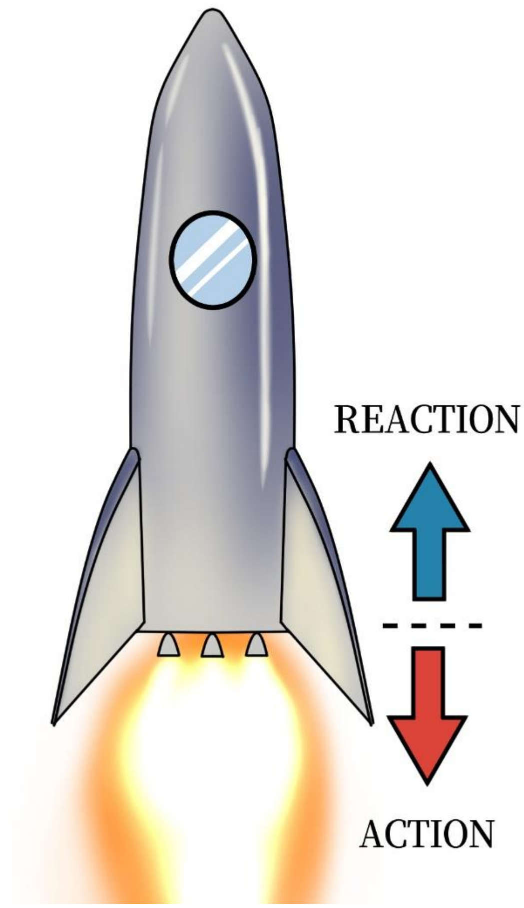
For every action, there is an equal and opposite reaction.

What Newton was saying with this law was that when a force acts on an object there is a force of the same value that acts in the opposite direction. An example of this is you sitting on your chair. There is the force of your weight (gravity) pulling you down and there is the chair pushing up.



You can see that this must be true because otherwise you would just fall through the chair (and then the floor and then the Earth).

Newton's third law of motion is what is happening with a rocket launch as well.



As the hot gas is ejected out of the bottom of the rocket there is a reaction force that sends the rocket shooting up into the air.

Think About It!!!

☞ To launch 1kg into space it costs about $18,000!!! Why do you think it is so expensive? What needs to be bought to launch that 1kg into orbit around the Earth?

☞ If you have ever seen video of a rocket launch you may have seen some parts of the rocket break away and fall back to Earth. This type of rocket is called multi-stage. Below you can see an illustration of a stage of rocket breaking off and falling back to Earth.

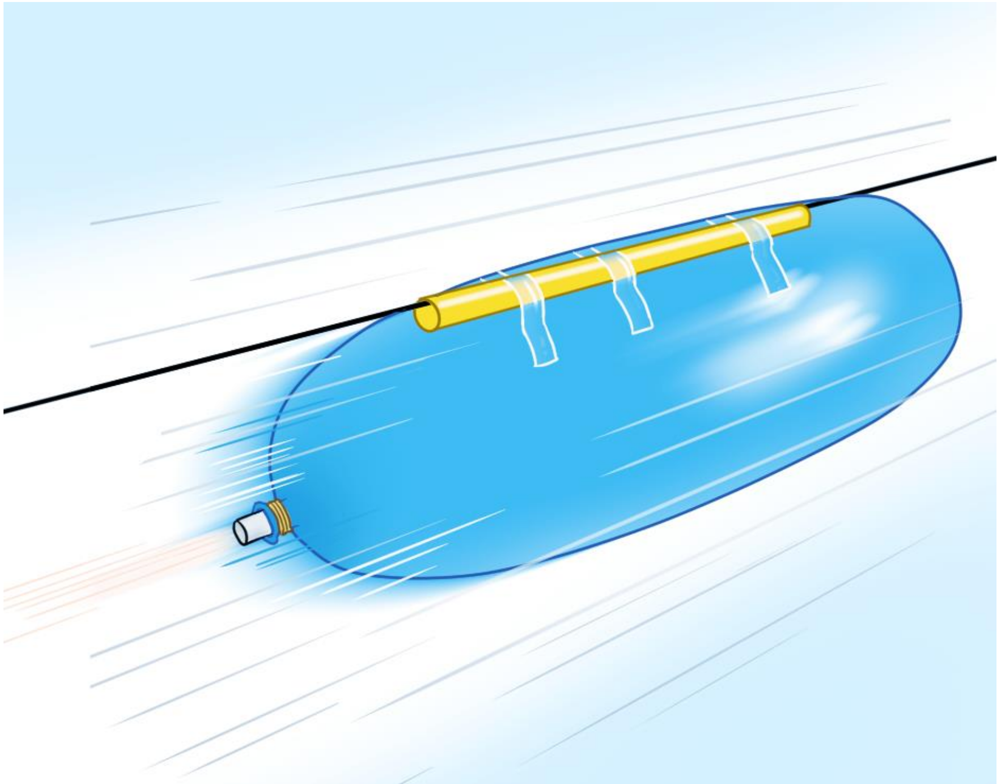
[14]

☞ Why do you think people use this multi-stage type of rocket? What is the big advantage?

[14] Image taken from https://spaceflightnow.com/2020/01/18/spacex-will-trigger-an-intentional-rocket-failure-to-prove-crew-capsules-safety/

Activity 1: Can we make a Model of a Multi-Stage Rocket?

☞ We are going to use balloons to make the model of our rocket. The air rushing out of the open end of the balloon is a good representation of the hot gases exploding out of the bottom of a launching rocket.[15]



1. First blow up a balloon. It is best not to inflate it too fully. Just hold the end shut. DON'T TIE IT.
2. Put the end of the balloon through the ring and hold the end against the side.
3. Put another balloon about halfway through the ring and blow it up. You should blow it up enough so that it presses the end of the first balloon against the side of the ring. You should be able to let go of the first balloon without the air escaping. This can be difficult and you will find it easier to work in pairs. DON'T TIE EITHER BALLOON.
4. Tape the balloons to the straws that your teacher has setup for you.

[15] Activity idea from https://www.sciencebuddies.org/teacher-resources/lesson-plans/two-stage-balloon-rocket#lesson

Think About It!!!

What do you think will happen when you let go of the second balloon?

☞ Let go of the end of the balloon. Describe here what happened. This is not an easy experiment to get right first time. So don't get frustrated, try to workout what went wrong and try to fix the issue.

☞ Do you think you can make your rocket go further? What would you change or improve on your rocket?

☞ Try out one of your suggested improvements. Did your rocket go further this time?

Lesson 3 Closing Thoughts: Self-Evaluation

What is being evaluated?	Rating Scale			
	Excellent	Good	Average	Poor
What issue(s) is investigated in this lesson: ________________________________				
What is your understanding of the issue(s) presented in this lesson?				
What is your scientific understanding of the issue(s)?				
How well did the experiment help with your understanding of the issue(s) of this lesson?				
What is your understanding of how to improve the distance travelled by the balloon rocket?				

Lesson 4: What Does Your Colony Need to Thrive?

Lesson 4 Opening Thoughts: What do Humans Need to Survive?

In lesson 2 we talked briefly about what humans need to survive. Let's look at some of the issues that would need to be addressed for humans to survive on a colony on another planet. We are going to look at three very important things that humans need, oxygen, water, and food. We want our colony to last for a very long time so we need to think of a way to produce or find all three.

Oxygen:

Humans need oxygen to breathe. Oxygen is a fuel our cells need to survive. Oxygen is an important building material for our bodies. Oxygen together with nitrogen and hydrogen make proteins that are used as a construction material for our cells. To make carbohydrates, the source of energy in our bodies, oxygen is combined with carbon and hydrogen.

In lesson 2 we saw that one possible way to produce oxygen is by the process of photosynthesis. There are, however, other ways to get the oxygen we need. NASA has developed a technology called MOXIE which is being tested on the Mars Perseverance rover. MOXIE uses electrolysis as well but uses the carbon dioxide of the Mars atmosphere to get its oxygen. Getting our oxygen from electrolysis will work but both ways require technology, and technology can breakdown. So is there a way to get our oxygen without technology. Yes, we can use the same way we get oxygen on Earth, plants. Plants generate oxygen through the process of photosynthesis. The problem with growing the plants is we need to make the soil fertile for them. Microbes can do this but it will take a long time.

Think About It!!!

Which way do you think would be best for us to get the oxygen we need?

Water: 

Water keeps our bodies healthy in many ways. Water is very important for in the process of food digestion, keeps body temperature normal, it also helps protect our joints, and our blood is about 90% water. It also keeps our brain working well. That's why doctors recommend we drink lots of water every day. The numbers vary but most doctors say we need about 10 to 15 cups of water every day.

There is water on Mars, but it is found as ice at both the north and south poles. We could melt this ice to drink but then the colony would need to be in these cold Polar Regions. It may also be possible to extract water from Mars atmosphere but surveys show there isn't much water present. It might also be possible to vapourise the water out of the Martian subsoil but it's possible there isn't any there to find.

Think About It!!!

What do you think is the best way to get the water for a colony?

Food:

Food is an important fuel for the human body. It is a source of nutrients, minerals, and vitamins. Humans can survive about 3 weeks without food, but as everyone knows we want to eat every day.

The oxygen and water can be found on Mars but there is no food. We have to find a way to grow our own. The soil does require some work to make it able to grow plants in, but it is possible for us to make the Martian soil suitable for growing plants. The choice is to decide which plants you would like to grow in your colony.

Plants are great as a food source but humans also need to have some way of getting protein in our diet. On Earth we get our protein by eating animals such as chickens, cow, pigs, etc. It will be very difficult (and expensive) to transport the animals from Earth to Mars. Many people think the solution is insects. Insects are a very good source of protein as they don't require much water or food for themselves. The problem is that many people think it's disgusting to eat bugs.

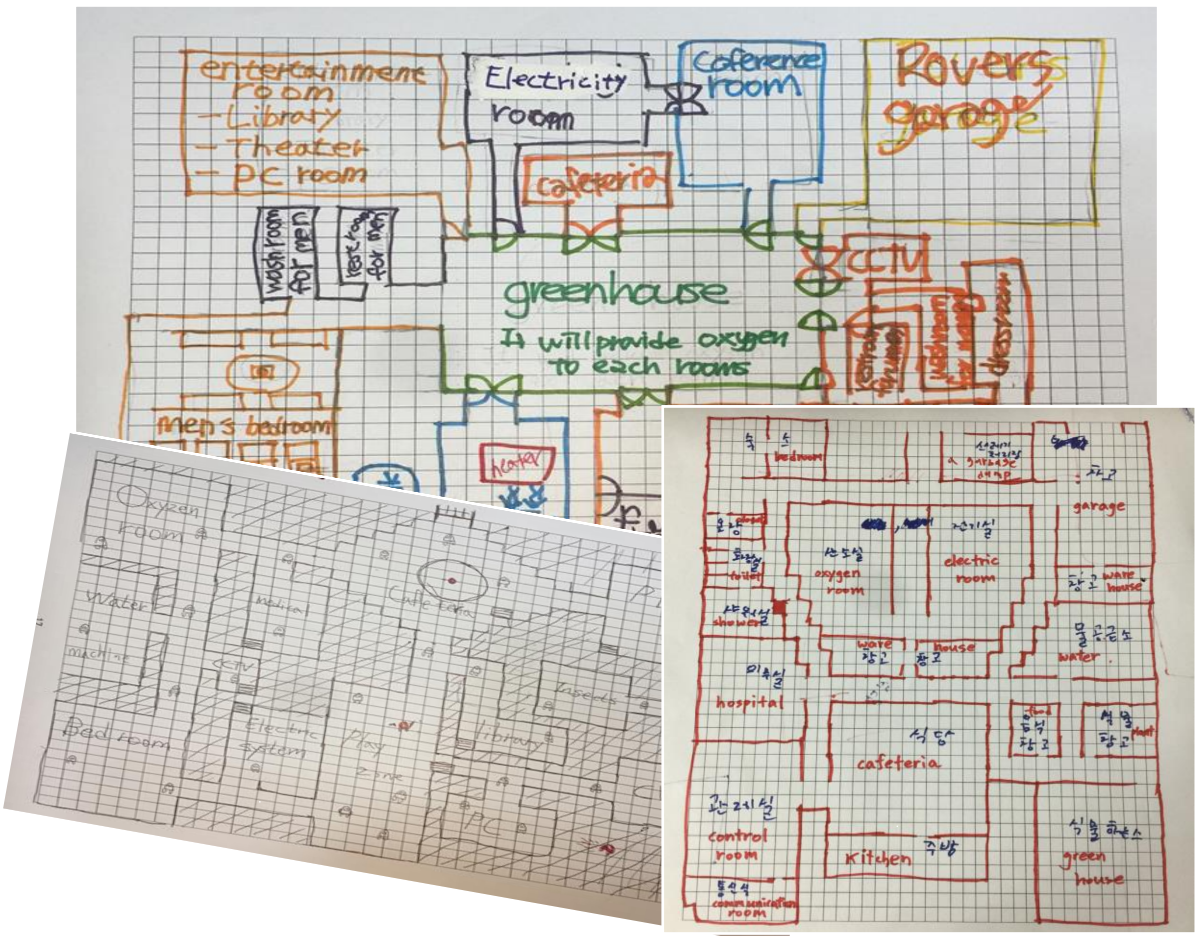
Think About It!!!

What food do think people should eat in your colony?

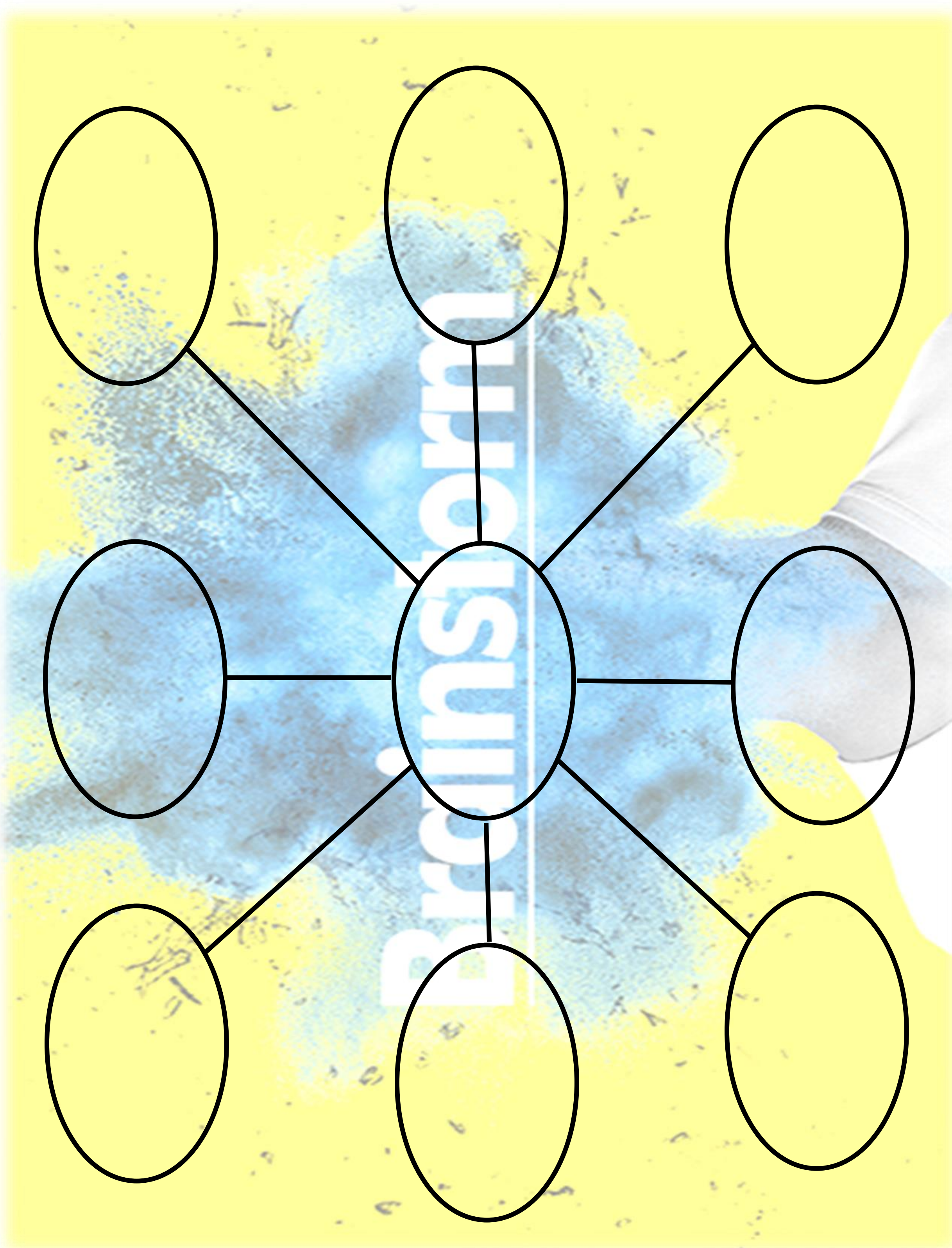
Activity 1: Brainstorm what you want to take to your colony.

With your group think about you want to be present in your colony. Your group needs to consider things that your colony will definitely need, such as, how to generate the oxygen, water, food, a place to sleep, and energy. Your group should also think about things you would like you to have in your colony. Remember you need something to keep everyone entertained.[16]

Cut out pieces of papers to represent the different buildings and areas of land that you what to have in your colony. You should keep things to scale. You don't want your bed to be tiny and the bathroom to be half the size of the colony. It is possible to have more than one floor to your colony but think what should be on the bottom floor carefully.



[16] Activity adapted from https://www.vivifystem.com/blog/2019/4/30/design-a-colony-on-mars-stem-project and some ideas from https://marsed.asu.edu/lesson_plans/marsbound


Brainstorm

Activity 2: Building a Rover for Your Colony

A rover is a very important tool for your colony. The rover can be used to scout the area for where you will be put your colony. You need to make sure the area is a good place for the colony.

Your teacher will provide your group with the kit to build your rover.

The course has been marked out with tape on the table. Your group should program your rover to follow the course. Your team will lose points for going over the lines of tape.

Activity 3: Exhibition Hall

Now it's time for the groups to present their colonies to the other groups. You should explain how to generate the oxygen, water, food, a place to sleep, and energy. Your group should also think about things you would like you to have in your colony. Remember you need something to keep everyone entertained.

Group Members:					
Colony's Name:					
Source of Oxygen	①	②	③	④	⑤
Source of Water	①	②	③	④	⑤
Source of Food	①	②	③	④	⑤
Place of Shelter	①	②	③	④	⑤
Source of Energy	①	②	③	④	⑤
Extras for the Colony	①	②	③	④	⑤

Group Members:					
Colony's Name:					
Source of Oxygen	①	②	③	④	⑤
Source of Water	①	②	③	④	⑤
Source of Food	①	②	③	④	⑤
Place of Shelter	①	②	③	④	⑤
Source of Energy	①	②	③	④	⑤
Extras for the Colony	①	②	③	④	⑤

Group Members:					
Colony's Name:					
Source of Oxygen	①	②	③	④	⑤
Source of Water	①	②	③	④	⑤
Source of Food	①	②	③	④	⑤
Place of Shelter	①	②	③	④	⑤
Source of Energy	①	②	③	④	⑤
Extras for the Colony	①	②	③	④	⑤

Group Members:					
Colony's Name:					
Source of Oxygen	①	②	③	④	⑤
Source of Water	①	②	③	④	⑤
Source of Food	①	②	③	④	⑤
Place of Shelter	①	②	③	④	⑤
Source of Energy	①	②	③	④	⑤
Extras for the Colony	①	②	③	④	⑤

Lesson 4 Closing Thoughts: Self-Evaluation

What is being evaluated?	Rating Scale			
	Excellent	Good	Average	Poor
What issue(s) is investigated in this lesson: ______________________________				
What is your understanding of the issue(s) presented in this lesson?				
What is your scientific understanding of the issue(s)?				
How well did design your own colony help with your understanding of the issue(s) of this lesson?				
How well did the exhibition hall help with presenting different solutions and approaches to solving the issue(s)?				

C: Computational Thinking Guideline

Introduction

This framework is a guide to be used by pre-service and in-service teachers and educators looking to study and learn about computational thinking (CT). The guide will provide you with a definition of each of the sixteen CT practices in the three categories of Data Practices, Modelling and Simulation Practices, and Computational Problem Solving Practices.

The guide will also provide information with how CT has changed this practice. It will look at how competency of this practice is used in the 21st Century.

There will then be two examples of this practice in action. The first will be an example of an activity where the students are strongly exposed to the practice. The second example will be of an activity that could be confused for the practice, but is reality a different CT practice

Finally, there will be some information about where the practice is commonly found in modules and lessons, and thoughts and opinion that the researcher reached through their study of CT.

Data Practices

Data has always been important in science experiments and the methods that scientists have used to deal with that data has evolved through the ages. As technology develops so does the ways in which scientists use it to collect, create, manipulate, analyze, and visualize their data.

The Data Practices consist of collecting data, creating data, manipulating data, analyzing data, and visualizing data.

Collecting Data (DP1)

Definition

This CT practice is the students gathering data through observation or measurement. Some examples of how a student would demonstrate this practice would be:

- Conducting an experiment themselves and recording the result.
- Downloading data from the internet of someone's experiment.
- Reading information, or watching a video, given to them by the teacher.
- Searching the internet, or printed material, for information.

What is New for Computational Thinking with This Practice?

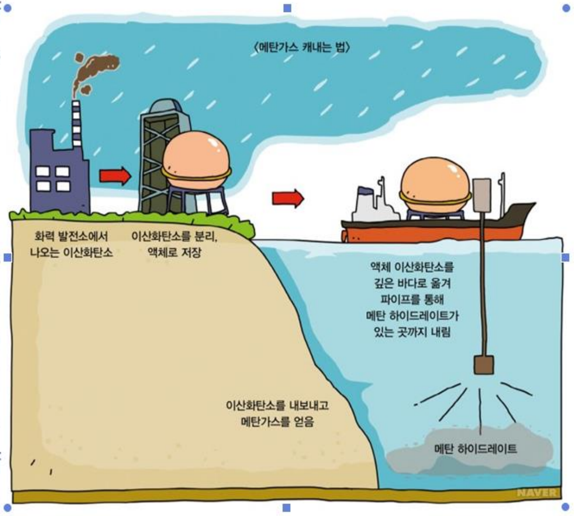
CT automation of the process allows for more data to be recorded, over greater time periods and with shorter intervals between measurements. Before CT the student could take measurements 5 or 6 times over the course of a 50 minute lab. Now with CT and setting up an Arduino the data could be recorded every minute and left running over night until class the next day. CT ability to handle bid data means that students can use historical data as well. For example, if they were studying climate change then they could collect data about precipitation and temperature for the previous 5, 10, or even 100 years.

Example of This Practice's Use

The following is an example from a science module that is teaching students about gas hydrate's structure and the difficulties of transporting it in solid, liquid, and gaseous form. The students also learn about the gas hydrate deposits around the island of Dokdo and the effects that it could have on the Korean economy.

The example can be found at the beginning of the first lesson of the module and it introducing the topic of gas hydrates to the students. The example is preceded by additional information and is followed by more questions.

Moreover, if methane explodes in the process of obtaining methane gas, it can cause serious environmental pollution or be a threat to the ecosystem.



How to mine gas hydrate

So how do you use gas hydrates? The solution to this is surprisingly from carbon dioxide. If you put carbon dioxide, which has a molecular structure similar to methane gas, next to the gas hydrate, methane will escape from the ice and carbon dioxide will be replaced instead. It's a revolutionary way to get rid of greenhouse gases and get clean, clean energy. You can't develop a gas hydrate for the East Sea right now, but are you really confident that the energy source of the future underneath our country's oceans will be substantial? You can use domestic fuel to get out of energy poverty that doesn't drop a drop of oil.

Refer to the above article to summarize the gas hydrate.

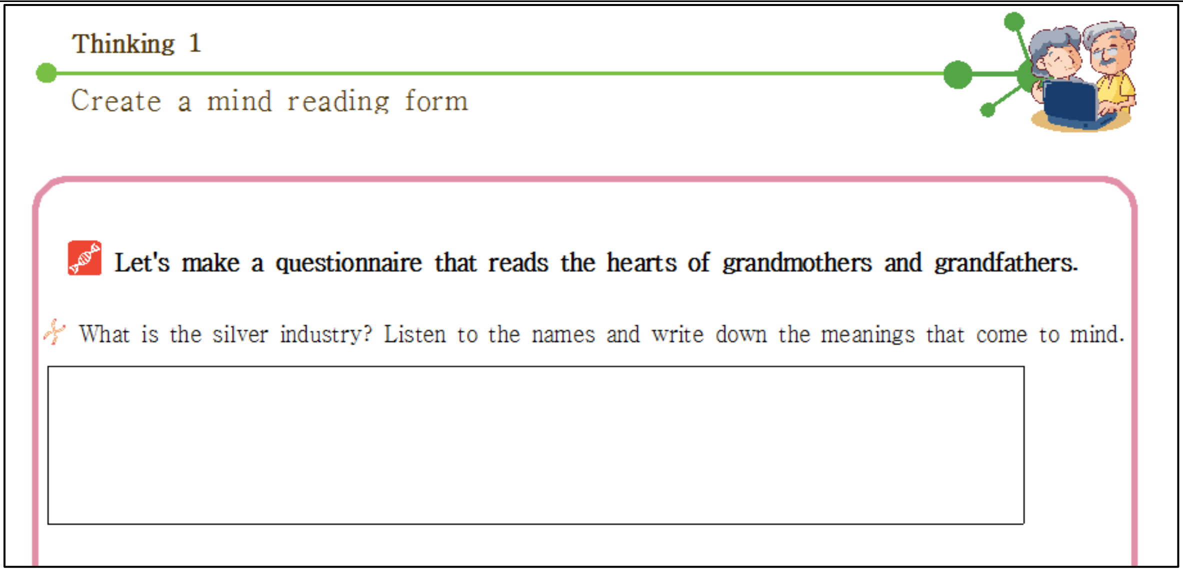
How is gas hydrate made?

What is the appearance of gas hydrates?

As can be seen in the first box of the example the students are presented with some information in the form of a paragraph and a picture. In the second box the students are then given some questions. The students need to read the information in the paragraph and picture to find the answers to the questions.

This is considered to be DP1 practice as the students have to collect data from a source, in this case the paragraph and picture, to answer the questions.

An Example of an Activity That Could Be Confused for This Practice



The above 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.

The above example is from the start of the second lesson of the module and the students are being asked to consider two examples of businesses that are struggling and how opening themselves up to the needs and wants of elderly people may help the businesses to thrive.

This example maybe confused as an example of DP1 because the students are being presented with information in the form of the two business examples. This is not DP1, however, as the students are not collecting the information from the examples they are reading the examples and then writing down what “meanings come to mind”. This means that the data is actually coming from the students and not the examples. As the students themselves are making the data this would really be an example of ‘Creating Data’ (DP2).

Where This Practice is Commonly Found in Lessons and Modules

This practice can be found anywhere in a lesson or module but it is commonly found at the start of lessons and modules. This is due to it being a way for teachers to introduce a topic / idea to the students. The teacher presents the students with some information that the students then study to collect data to answer the questions set by the teacher.

This practice is very often followed by the practices of ‘Manipulating Data (DP3)’, ‘Analyzing Data (DP4)’, and ‘Visualizing Data (DP5)’. This is the students performing some activity with the data they have collected.

Final Thoughts

The students should be collecting the data from a place that is not their own heads. If the students are making their own data from their thoughts and opinions then it should be considered as 'Creating Data (DP2)'.

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 an Activity That Could Be Confused for This Practice

Discover real problems through empathy interviews

■ Do something. Sympathetic interview

1)Follow these steps to conduct a sympathetic interview about the damage that occurs in your chosen disaster or disaster situation.

① Create key questions related to the damages that can be caused in the event of a disaster or disaster surveyed by the group. ex) Why do secondary damages occur when an earthquake occurs? Who is the biggest victim of the earthquake? Etc	

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 phenomena. 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.

Manipulating Data (DP3)

Definition

Reshaping the data to be in the desired or useful configuration. Includes the sorting, filtering, cleaning, normalizing, and joining of datasets. Some examples of how a student would demonstrate this practice would be:

- Reordering of data so that it is highest to lowest.
- Collating data from different sources to have a dataset that covers the required range.

What is New for Computational Thinking with This Practice?

Computers allow for data to sorted, filtered, cleaned, normalized and joined quickly and easily. Something that would take hours and hours of work to do manually, with a high chance of making a mistake can be done with the click of a button, with very little chance of a mistake.

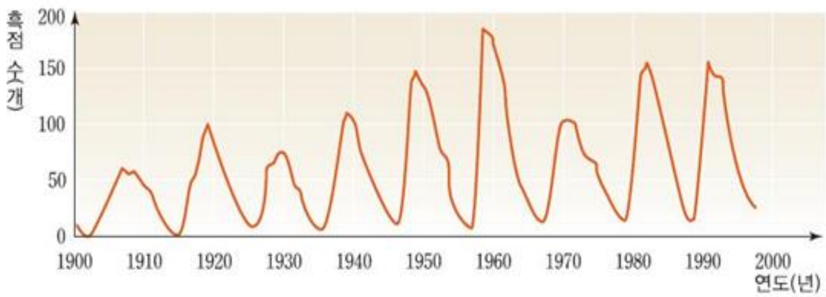
Example of This Practice's Use

The following example is from a science module that teaches students about different types of space events, such as, solar flares, asteroid collision, and supernova, and the effects that they can have on humans and technology.

The activity in the example has the students looking at data about the number of observed sunspots over the last 100 years. The students are writing down the years in which the number of sunspots reached a peak. This activity is considered to be manipulating data (DP3) as the students are changing the data from one form, a graphical representation, into another form, numbers in a table.

Sunspots and Solar Activity

The following is an observation of sunspot numbers over the last 100 years.



[Source-Venus Textbook Science 3]

1) Find the year with the maximum number of sunspots and record it in the table below.

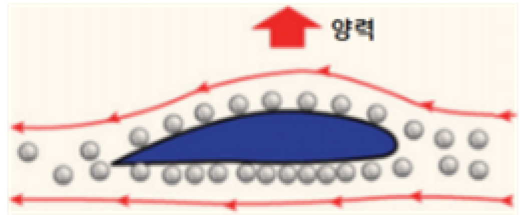
division	1	2	3	4	5	6	7	8	9
Maximum year									
interval									

An Example of Activity That Could Be Confused for This Practice

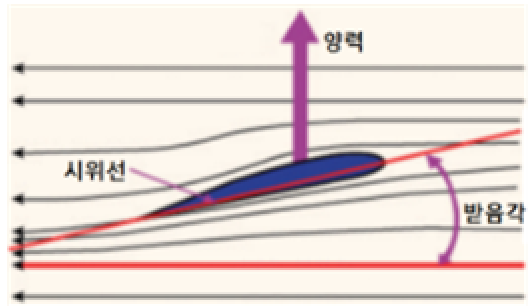
The following example is from an engineering module where the students are learning about airplanes. The module starts with the students learning about the rules that govern what items are prohibited when travelling on an airplane and finishes with the students learning about the forces that act on an airplane wing that allows for it to fly.

The example is found at the end of a long series of activities in the second lesson of the three lesson module. The students are considering the forces that are acting on two different wing set-ups. The wings are the same, but the angle of attack has changed.

5. Let's learn more about (____), the force that makes a plane float. (_____) Has two main causes, one due to the pressure difference above and below the wing and the other due to the angle of attack.



The aircraft moves faster on the wings. The faster the movement of the gas, the farther the molecules are, the smaller the pressure. The plane is forced upward by the pressure difference. To make this effect even bigger, the shape of the airplane's wing is modified.



Consider the angle of attack, another cause of lift. Angle of attack is the angle that the wing of the aircraft makes with the horizontal plane. Larger angles of attack provide greater lift, but also increase drag, which impedes propulsion.

Here is a picture of two wings with different angles of attack. In each case, let's graphically describe the force that the wing receives from the air and the resulting lift.

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This activity could be confused as being 'manipulating data (DP3)' as it could be considered that the students are taking the information they have learnt in the previous activities with paragraphs of information, diagrams, and figures and changing that into arrows showing the forces in action on the two different wing set-ups. However, this activity is an example of the 'visualizing data (DP5)' practice. The aim of the activity is for the students to make a visual representation of the information they have learnt about the forces. The visual representation is for them to better understand (and explain to others) how the forces interact to produce different resultant motions on the two wings.

Where This Practice is Commonly Found in Lessons and Modules

This practice can be found anywhere in lessons or modules. This practice is not often found alone, but in partnership with other data practices. An example of this would be students reorganizing the dataset so that they can make a graph depicting the results.

Final Thoughts

This practice is not difficult to assign. Look for the students changing something about the data, but this should not be changing the data visually. If it is a visual change then it 'visualizing data (DP5).

Analyzing Data (DP4)

Definition

Looking for patterns, or anomalies, defining rules to categories data, and identifying trends and correlations**.** Some examples of how a student would demonstrate this practice would be:

- Students analyze a dataset to see if there is a difference between different variables.
- Students read a paragraph of information and then pick out the answers to questions from the paragraph.

What is New for Computational Thinking with This Practice?

CT is an effective tool for data analysis especially with the advent of big data. An example of data analysis would analyzing the data from thousands of weather station around the world to see if there has been any changes in the average precipitation and temperature.

Example of This Practice's Use

The following example is from an engineering module of the students studying about fine dust. The students study about the nature of fine dust and the changes in fine dust concentration in different areas of Korea. They then learn about different methods of reducing the amount of fine dust caused by cooking.

The example can be found near the end of the first lesson of the module. The activity involves the students find the average concentrating of fine dust in the different regions of Korea from the airkorea website (collecting data (DP1)) and then analyzing the data to see if there is a difference between the regions.

☑ Check the average daily atmospheric information (PM10, PM2.5) for each real-time trial and color by region according to the grade.

	Seoul	Busan	Daegu	Incheon	Gwangju	Daejeon	Ulsan	Gyeonggi	Gangwon	Chungbuk	Chungnam	Jeonbuk	Jeonnam	Sejong	Gyeongbuk	Gyeongnam	Jeju
PM_{10}																	
$PM_{2.5}$																	

Forecast content	ranking (μg/㎥)			
	Good	Usual	Bad	Very bad
fine dust PM_{10}	0~30	31~80	81~150	More than 151
fine dust $PM_{2.5}$	0~15	16~50	51~100	More than 101

① Is there a difference in fine dust concentration in each region?

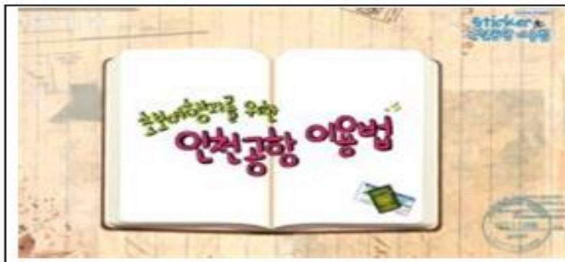
This would be considered to be an example of 'analyzing data (DP4)' as the students are looking at the dataset to look for differences.

An Example of Activity That Could Be Confused for This Practice

The following example is from an engineering module where the students are learning about airplanes. The module starts with the students learning about the rules that govern what items are prohibited when travelling on an airplane and finishes with the students learning about the forces that act on an airplane wing that allows for it to fly.

In the example activity the students are watching a video to learn about how to successfully use an airport. There are questions about what time the passengers should arrive at the airport and what items can and cannot be packed in both the carryon and checked bags. Not shown in the example is some more questions concerning going through security, duty-free shops and boarding.

1.How to use Incheon Airport for travelers

		
Video length	3 minutes 25 seconds	https://www.youtube.com/watch?v=3IFHGWgx154

Based on the video, let's take a look at the process of arriving at the airport and leaving.

Let's summarize how to use the airport by answering the following questions:

When you arrive at the airport you have to go through the places of me, da, la. Based on the video, write down the appropriate words for each.

가. Arrival at the airport: Arrival (   ) hours before departure time

나. Get your boarding pass at the counter of your airline and load your baggage. Small items must be checked in baggage in advance, and some items are not allowed in baggage.

- Small items: ___ , ________ , ________ , ________ etc

Baggage Prohibited Items _______ , _________ etc

This example could be confused for 'analyzing data (DP4)' as the students are finding the answers to questions with data from the video. The activity is, however, an example of 'collecting data (DP1)' as the students are not doing an analysis of the video they are finding the answers from the data presented in the video.

Where This Practice is Commonly Found in Lessons and Modules

This practice can be found anywhere in lessons or modules. This practice is not often found alone, but in partnership with other data practices. An example of this would be students analyzing the data they collected during an experiment (collecting data (DP1)), looking for patterns, or correlations, before making a visual representation of the data (visualizing data (DP5)).

Final Thoughts

This practice is not difficult to assign. This practice can be observed when the students are making some decision about the data not just picking out an answer. That would be an example of 'collecting data (DP1)'.

Visualizing Data (DP5)

Definition

Make a visual representation of the data. Some examples of how a student would demonstrate this practice would be:

- Creating a pie-chart could be created to show people the relative CO_2 production of various household activities.
- Colouring a map to show the average temperatures of the different regions of the year.
- An interactive computer program that shows the effect of raising temperatures on the polar ice and the resulting raising sea levels.

What is New for Computational Thinking with This Practice?

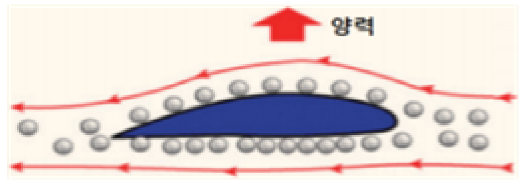
CT makes it very easy to quickly and cheaply produce graphs and charts. The purpose of the graphs is too make it much easier for people to understand the relevant information. CT also makes it possible to make an interactive display that allows people to control variables and see the results.

Example of This Practice's Use

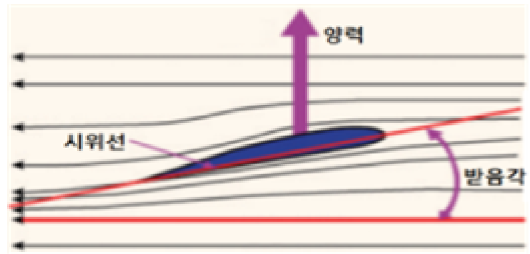
The following example is from an engineering module where the students are learning about airplanes. The module starts with the students learning about the rules that govern what items are prohibited when travelling on an airplane and finishes with the students learning about the forces that act on an airplane wing that allows for it to fly.

The example is found at the end of a long series of activities in the second lesson of the three lesson module. The students are considering the forces that are acting on two different wing set-ups. The wings are the same, but the angle of attack has changed.

5. Let's learn more about (_____), the force that makes a plane float. (______) Has two main causes, one due to the pressure difference above and below the wing and the other due to the angle of attack.



The aircraft moves faster on the wings. The faster the movement of the gas, the farther the molecules are, the smaller the pressure. The plane is forced upward by the pressure difference. To make this effect even bigger, the shape of the airplane's wing is modified.



Consider the angle of attack, another cause of lift. Angle of attack is the angle that the wing of the aircraft makes with the horizontal plane. Larger angles of attack provide greater lift, but also increase drag, which impedes propulsion.

Here is a picture of two wings with different angles of attack. In each case, let's graphically describe the force that the wing receives from the air and the resulting lift.

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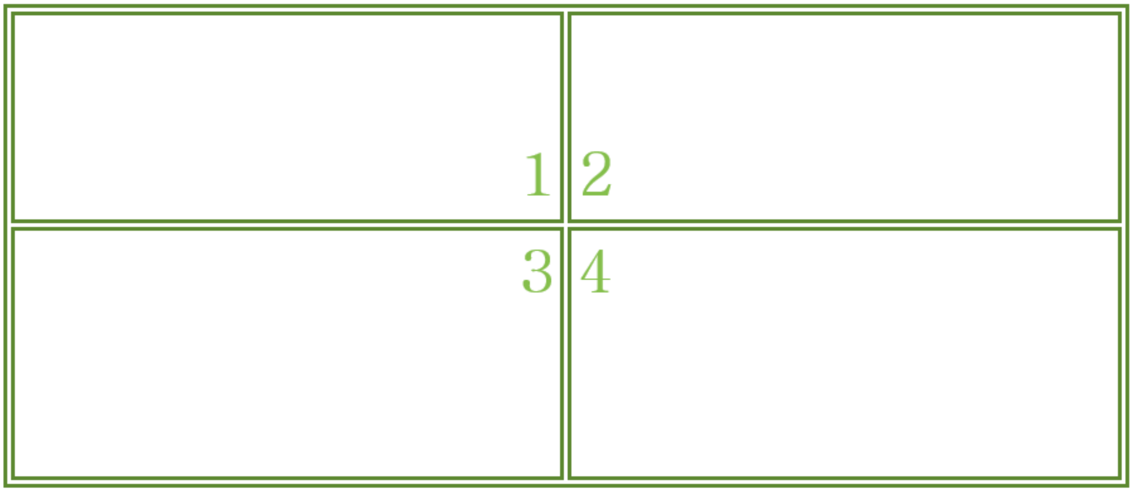
This activity is an example of the 'visualizing data (DP5)' practice. The aim of the activity is for the students to make a visual representation of the information they have learnt about the forces. The visual representation is for them to better understand (and explain to others) how the forces interact to produce different resultant motions on the two wings.

An Example of Activity That Could Be Confused for This Practice

3. Complete the 4-cut cartoon based on the situation you imagined. Let's organize the comics so that we can clearly see the situation where we need them.



The above 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.

In the example the students are making a four panel cartoon or a situation where a piece of technology is being used to help elderly people in their daily lives.

This activity might be confused as being ‘visualizing data (DP5)’ as the students are drawing picture (the cartoon) to showcase their ideas for how the technology could help elderly people. However, it an example of ‘constructing a computational model (MS5)’. The cartoon is a model of how the technology would be used.

Where This Practice is Commonly Found in Lessons and Modules

This practice can be found anywhere in the lessons or modules but is often the final step of a series of activities involving the collection, manipulation, analysis, and finally visualization of the data. For example, the students would conduct an experiment, organize the data, analyze it for patterns and then finally produce some graph depicting the results.

Final Thoughts

This is not a difficult practice to assign. Look for students making a visual version of their data.

Using Computational Models to Understand a Concept (MS1)

Definition

This practice is using a computational model so the students can form an interpretation of the phenomena being studied. Some examples of how a student would demonstrate this practice would be:

- Students adjusting the variables on a model to observe how the change affects the outcome.
- Students experiencing how changes in the environment affect their ability to perform tasks.

What is New for Computational Thinking with This Practice?

Computational models give students more control (than the natural world) to investigate concepts. Using a computational model to observe the relationship between different methods of energy production (oil, natural gas, nuclear, or renewable) and the amount of CO_2 in the atmosphere. Formulas or animations can be used to help with understanding of the concepts for students. The model can be chosen by the students or it can be provided by the teacher.

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.

The activity can be found towards the start of the first lesson of the module. It is at the start of a series of activities looking at how technology can help elderly people. The activity is designed to give the students an understanding of the difficulties that elderly people face in performing everyday tasks. This is achieved by using items to impair the students' eyesight and movement.

1. Choose a group of similar items for the elderly.	
	
Eye Team: Glaucoma, Cataract Glasses	Back Team: Foldable Back guard
	
Leg Team: Knee, Ankle Sandbag	Arm Team: Wrist, Elbow, Gloves

With the object of your choice, you can complete the following missions:

team	mission
Eye team	- **Thread the needle** - **Read the newspaper out loud** - **Walk without stepping on the line**
Back team	- **Take out 5 things high up** – **Squat and get up 10 times**
Leg team	- **Go up and down stairs from the first floor to the third floor** - **Crouch and sit up 10 times**
Arm team	- **Line up 10 small things (blocks) on high ground** - **3 small paper dolls cut with scissors**

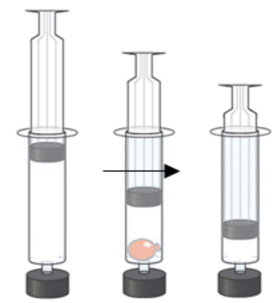
This activity is considered to be the 'using computational models to understand a concept (MS1)' as the students are being introduced to how elderly people can have difficult performing everyday tasks because of limitations in their eyesight and movement.

An Example of Activity That Could Be Confused for This Practice

The following example is from an engineering module where the students are learning about airplanes. The module starts with the students learning about the rules that govern what items are prohibited when travelling on an airplane and finishes with the students learning about the forces that act on an airplane wing that allows for it to fly.

The activity in the example is the third activity of the first lesson of the module. It is preceded by two activities looking at what objects it is prohibited to take onto an airplane. The activity starts with a thought exercise where the students are asked to consider why it would prohibited to carry a basketball onto an airplane.

1. Bigger balloons without blowing
   가. Blow the balloon into the syringe and close the syringe outlet with a rubber stopper.
   나. How does the balloon change size when the piston is pushed in? Let's first predict the size change of the balloon and record the experiment result



Prediction: ______________ Experimental Results: ___________________

This activity might be confused for 'using computational models to understand a concept (MS1)' as the students are observing how the balloon will inflate and deflate depending on the movement of the piston. The activity is actually considered to be 'using computational models to find and test solutions (MS2)'. This is because the students make a prediction as to what they think will happen with the balloon before moving the piston. As the students make this prediction they are testing their solution not understanding the concept.

Where This Practice is Commonly Found in Lessons and Modules

This practice is often found at the start of activities. It is an often used technique by teachers to introduce the concept / phenomena that will be studying in the class that lesson. It is a good process for students to learn about a concept / phenomena as the students learn by doing rather than just listening to information presented by the teacher.

Final Thoughts

This practice can be very easily confused for the 'using computational models to find and test solutions (MS2)' as the two practices can in real life be very similar to each other. The two practices are also often found together.

Using Computational Models to Find and Test Solutions (MS2)

Definition

Having formed the concepts of the phenomena, computational tools allow students to find, test and justify a solution. Some examples of how a student would demonstrate this practice would be:

- The students can quickly, easier, and cheaply test their possible solutions for which type of renewable energy production (solar, wind, tidal etc.) would be best for the intended location.
- The students can test their understanding of a concept by to testing to see if their predicted solution is correct.

What is New for Computational Thinking with This Practice?

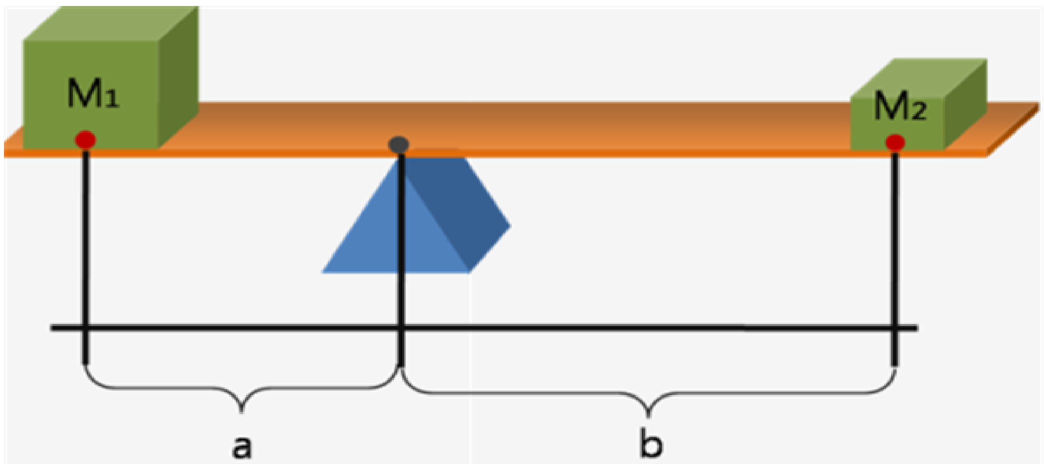
Computational models help students to apply concepts of a phenomena. CT allows for the possibility to test different solutions quickly, easily, safely and cheaply.

Example of This Practice's Use

The following example is from an engineering module where the students are learning about airplanes. The module starts with the students learning about the rules that govern what items are prohibited when travelling on an airplane and finishes with the students learning about the forces that act on an airplane wing that allows for it to fly.

The activity is the first activity of the third and final lesson of the module. With this activity the students are find the relationship between the weights and the distance of the weights to the centre lever. This is considered to be MS2 as the students are testing their understanding of centre of gravity.

3. If you look at the figure and want the lever to equilibrate, build a relationship between the weight of the lever and the position of the weight (the distance from the center of the lever).



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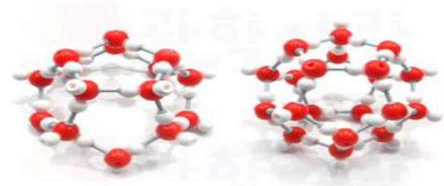
4. When the lever is in equilibrium, which is the center of gravity of the lever?
What happens to the lever if it is not balanced?

☞

An Example of Activity That Could Be Confused for This Practice

The following is an example from a science module that is teaching students about gas hydrate's structure and the difficulties of transporting it in solid, liquid, and gaseous form. The students also learn about the gas hydrate deposits around the island of Dokdo and the effects that it could have on the Korean economy.

The activity can be found at the end of the first section of the first lesson of the module. The section has the students studying about the properties of gas hydrate. This is an activity to teach them about the structure of gas hydrate.

[Step 1] First, make 20 water molecule models by connecting two hydrogen (white beads) to one oxygen (red beads). 	[Step 2] Make one methane (4 white beads + 1 black bead) and fasten with mortar-type connecting rod. 
[Step 3] Connect water molecules to form a pentagon, complete them, and make them opposite each other so that they are symmetrical. 	[Step 4] Continue to connect water molecules to form a pentagon to create a three-dimensional solid clathrate. 
[Step 5] Connect methane to the completed three-dimensional water molecule. 	[Step 6] Now, the fastening bar (heavy) is inserted into the red bead (oxygen) of the outermost water molecule and completed. 

The activity could be confused for 'using computational models to find and test solutions (MS2)'. The confusion come from the belief that the students are finding the solution for the structure of gas hydrate. The students are not finding or discovering anything themselves however. They are following the instructions and it is also the first time the structure has been introduced to them. The activity should therefore be considered to be 'using computational models to understand a concept (MS1)'.

Where This Practice is Commonly Found in Lessons and Modules

This practice can be found in two different types of place. It can be found at the start of activities as a way for teachers to get students thinking about their knowledge of the concept / phenomena. It can also be found at the end of activities will the students using the models to test the solutions their developed earlier in the activity.

Final Thoughts

This practice can easily be confused with 'using computational models to understand a concept (MS1)' as the two practices can in real life be very similar to each other. The two practices are also often found together.

Assessing Computational Models (MS3)

Definition

Assessing how faithfully the model represents the phenomena. Students assess what assumptions have been made and how do they effect the behavior of the model. Some examples of how a student would demonstrate this practice would be:

- The students can check the answer produced by their model against the established correct answer to see if the model is working as intended.
- Is the model actually modelling the required concept / phenomena or is only modelling something similar.

What is New for Computational Thinking with This Practice?

The student can use the computational models to assess suggested models before attempting to construct the model or assess models given to them by the teacher. The accepted answer that the model should give can be found on the internet to check the right result is being given by the model.

Example of This Practice's Use

The following 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 example can be found towards the end of the final lesson of the module. In the activity the students are preparing an overview of the warning device their group made in order to present the information to their classmates. There are considering what are the pro and cons, benefits, and areas for improvement for their device.

• Pros and cons of the work:

• Benefit:

• Improvement ideas:

This activity is considered to be 'assessing computational models (MS3)' as the students are judging the good and bad aspects of their device.

An Example of Activity That Could Be Confused for This Practice

The following example is from an engineering module where the students are learning about airplanes. The module starts with the students learning about the rules that govern what items are prohibited when travelling on an airplane and finishes with the students learning about the forces that act on an airplane wing that allows for it to fly.

The activity can be found at the start of the second lesson. In the activity the students are looking at three different ideas from Da Vinci about trying to fly. The students are comparing the three ideas to present day flying objects and considering how they are similar and different.

Da Vinci's idea	Compare with the current object
	☐ (name) ☐ (similarity) ☐ (Different points) ☐
	☐ (name) ☐ (similarity) ☐ (Different points) ☐
	☐ (name) ☐ (similarity) ☐ (Different points) ☐

This activity could be confused for ‘assessing computational models (MS3)’ as the students are looking at different methods of flight. However, the students are not assessing the ideas for their good and bad points. They are comparing Da Vinci’s ideas with modern day objects. Due to this comparison the activity is actually an example of ‘assessing different approaches / solutions to a problem (PS4)’.

Where This Practice is Commonly Found in Lessons and Modules

This practice can be found anywhere in the lessons and module. It is commonly found in partnership with the ‘designing computational models (MS4)’ practice.

Final Thoughts

This practice is very easily confused with both 'choosing effective computational tools (PS3)' and 'assessing different approaches / solution to a problem (PS4)'. During the researcher's study of CT they came upon an activity where the students had to decide between two self-driving cars that had different programming in what to do when faced with decisions of a moral / ethical nature. An example of this would be that the car cannot avoid an accident and will either collide with an elderly person or a young child. One car is programmed to choose to hit the elderly person and the other is programmed to collide with the young child. The students are asked to choose which car they would buy. There was a lot of debate about this activity and eventually it was decided to be an example of 'assessing computational models (MS3)', but there is still room for debate.

Designing Computational Models (MS4)

Definition

Making technological, methodological, and conceptual decisions. Characterize the relationship between components, and the data the model will produce. Also the make decisions about what assumptions need to be made. Some examples of how a student would demonstrate this practice would be:

- Designing a photo bioreactor. What shape should the reactor be, can mirrors be put around the reactor to increase efficiency, which species of algae would generate the most oil, and can the algae monitored automatically to make sure it is harvested at the best time?

What is New for Computational Thinking with This Practice?

The nature of CT does not change this practice that much from what would be done in a more analog situation. The types of decisions being made is not that much changed, but the results of the decision could be affected with the availability of making a model on the computer rather than a physical model.

Example of This Practice's Use

The following example is from a science module that teaches students about different types of space events, such as, solar flares, asteroid collision, and supernova, and the effects that they can have on humans and technology.

This is the last activity of lesson 2. The students are beginning the design of an app to warn about space weather. The students make a paper based app design. This activity is considered to be 'designing computational models (MS4)' as the students are beginning the process of designing their app by deciding on such things as title, who would use the app, the concept, and the content. This is considered to be the MS4 practice as the student are designing their model.

🕮 **Basic design of space weather paper prototype**

Let's design a smartphone application paper prototype based on information related to space weather.

What is the Smartphone Application Paper Prototype?

Even if you don't have coding skills, if you have an idea for an app or program, you can simply draw the program you want to draw on paper and create a video that you can turn into a movie to show a working model of the application. It is one of the most beneficial methods in that it is low cost and easy to find and reflect the problem.

An Example of Activity That Could Be Confused for This Practice

The following example is from an engineering module that has students studying about environmental destruction and animal extinction. The students then consider how technology, especially drones, can be used to survey and restore ecosystems.

The activity can be found at the end of the first lesson but is the start of the design process of the students making their own ecological model. As it is part of the design process is maybe confused to be 'designing computational models (MS4)'. However, what the students are doing in this activity is considering the best materials for modelling the different aspects of their model. As the students are making choices about which materials would be best the practice they are demonstrating is actually, 'choosing effective computational tools (PS3)'.

4-3 Explore ecology around us

Think about the eco-environment model you want to express using the materials. Let's see.

Material to be picked up (excluding disposables): Carrara, Blue Moss, Colored Paper, Tinfoil, Anvil, Cellophane Paper

Three ingredients from the individual or group:

만들고 싶은 요소 The element you want to create	표현방법 Expression method	비고(재료) Remarks (material)

Where This Practice is Commonly Found in Lessons and Modules

This practice is commonly found towards the end of lessons. The students learn about the properties and characteristics of a concept / phenomena and then design their own model. This practice is nearly always combined with 'constructing computational models (MS5)' as the building of the design is a logical next step.

Final Thoughts

This is not a difficult practice to assign.

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.

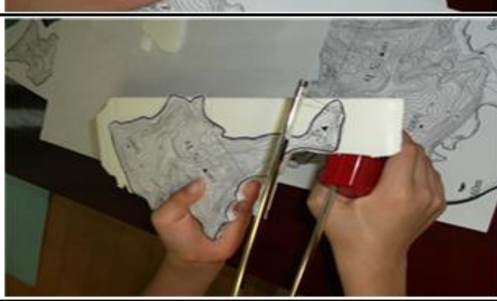
What is New for Computational Thinking with This Practice?

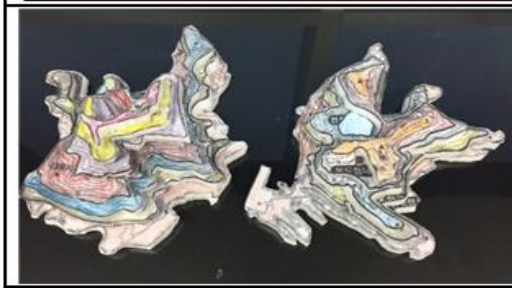
There is not a change in the fundamental nature of this practice with the advent of CT. The difference now being that the construction of the model maybe on the computer rather than a physical model.

Example of This Practice's Use

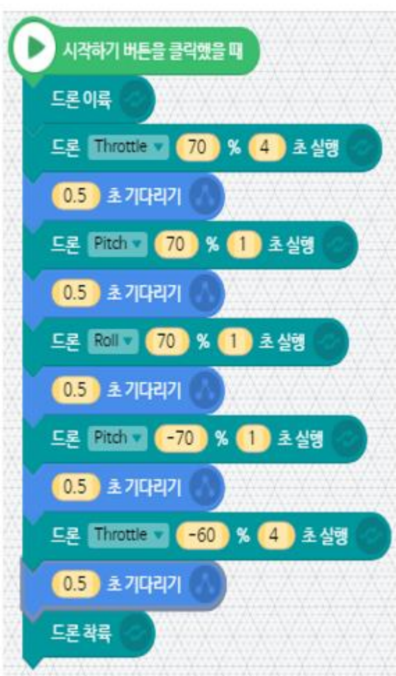
The following example is from a science module about the island of Dokdo. The students learn about how Dokdo was formed, the different types of rock, and what rocks can be found on Dokdo.

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.

	▪ Crop Topographic Height - Cut the topographic map of the 20-meter west and east road provided by height - In the group, it is good to make a three-dimensional map by dividing the height to be produced for each individual.
	▪ Pasting to Topographic Woodlock - Attach the topographic map, cut by height, to the woodlock using glue. - One piece of four-fold Wood Rock can be used.
	▪ Trim Wood Rock by Height - Use a wood lock cutter to cut the wood lock by height. - Wood lock cutters use electricity and have heating wires, so pay attention to safety.

	▪ Stacking Woodlocks to Fit Position and Height – Accurately stacks woodlocks to determine heights and topographic map locations, and complete stereoscopic maps.
	▪ Decorate the completed Dokdo stereo map – Each of the completed Dokdo 3D maps will be creatively decorated using various things such as colored pencils and colored paper. – You can decorate at any time during or after the completion of the three-dimensional map.

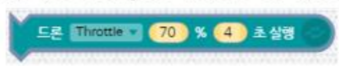
An Example of Activity That Could Be Confused for This Practice



● 

Bring it up and the drone will rise.

Enter the output value of the drone as follows:

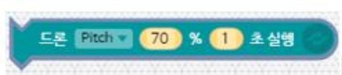


After 4 seconds, it rises about 2m.

●**To distinguish after receiving the signal**

Connect

●**For the drone to move forward**



Bring it.

●**1 m to the right**

Connect

●**As the drone rises slowly**

Connect.

The above example is from an engineering module that has students studying about environmental destruction and animal extinction. The students then consider how technology, especially drones, can be used to survey and restore ecosystems.

The above activity can be found towards the end of the final lesson of the module. The activity is showing the students how to program a drone to follow a search pattern to survey an area. They are going to use this drone to make a survey of the ecological model they designed and constructed earlier in the module.

This activity maybe confused as ‘constructing computational models (MS5)’ as the students are making a program to control the drone. However, this activity is programming and in CT this is its own individual practice, ‘programming and algorithms (PS2)’.

Where This Practice is Commonly Found in Lessons and Modules

This practice is often found at the end of lessons and modules. It is often the final activity of the lesson. The students learn about a concept / phenomena, design a model, and then finish by constructing that model.

Final Thoughts

This model is very often found with the practice of ‘designing computational models (MS4)’ and the process of design and then construction of a model is a very common activity.

Decomposing Problems to Allow for a Computational Solution (PS1)

Definition

Breaking the problem down into sub-problems and reframing them in such a way that a computational model can be used to find a solution. Some examples of how a student would demonstrate this practice would be:

- Breaking down a large and complex problem into more manageable parts. For example, the causes of climate change is a complex issue, and so the students could be asked to consider what might be some possible causes, coal power plants, cars, deforestation, etc.
- Introducing a topic by having the students consider the different factors that could be affecting the phenomena.
-

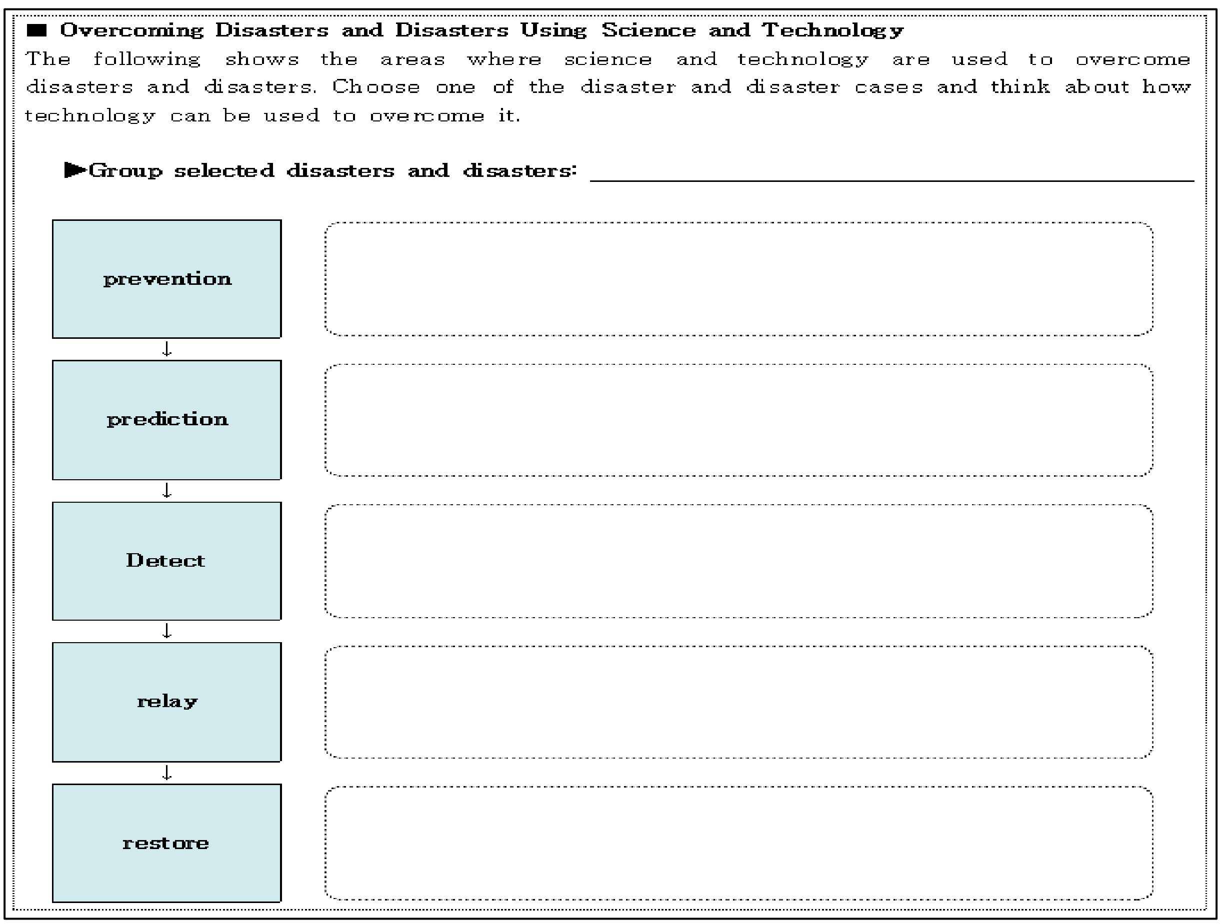
What is New for Computational Thinking with This Practice?

Decomposing has always been a part of finding a solution for a problem. This has not changed for CT. With CT, however, there becomes a need to set the boundaries of each factor distinctly as a computer cannot accept ambiguity.

Example of This Practice's Use

The following 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. This is in the first lesson of the module. Before this the student are discussing natural and man-made disasters. This activity is introducing the idea of using science and technology to overcome disasters.

In this activity the students are breaking down the issue of how to overcome a disaster into the sub-problems of prevention, prediction, detect, relay, and restore. This is considered to be the PS1 practice as the students have to decompose the issue into the small parts in order to make the issue solvable.



■ Overcoming Disasters and Disasters Using Science and Technology

The following shows the areas where science and technology are used to overcome disasters and disasters. Choose one of the disaster and disaster cases and think about how technology can be used to overcome it.

►Group selected disasters and disasters: ____________________

An Example of Activity That Could Be Confused for This Practice

1-1 Impact of Ecosystem Destruction and Species Extinction

Let's think about what's going to happen if ecosystem destruction and species extinction continue, as you see now.

http://news.naver.com/main/read.nhn?mode=LPOD&mid=tvh&oid=214&aid=0000319439]

http://www.ziksir.com/ziksir/view/4480]

Use plants and plants that are endangered and destroyed.

Discuss how people's lives, environmental pollution and ecosystem destruction affect each other Let's announce.

List the impact of ecosystem destruction and species extinction on humanity.

The above example is from an engineering module that has students studying about environmental destruction and animal extinction. The students then consider how technology, especially drones, can be used to survey and restore ecosystems.

The above example is the first activity of the first lesson of the module. The activity sees the students thinking about the causes and effects of ecosystem destruction and species extinction. This activity could be confused for 'decomposing problems to allow for a computational solution (PS1)' as it could be considered that the students are breaking the problem of ecosystem destruction and species extinction into the individual factors. However, the aim of the activity is not for the students to just break down the problem, it is for students to consider what are the most important causes and effects of the destruction and extinction. The activity should therefore be considered to be ‘creating computational abstractions (PS5)’.

Where This Practice is Commonly Found in Lessons and Modules

This activity is often found as the first activity of a lesson. It is used a way for teachers to get students thinking about the problem / issue at hand.

Final Thoughts

This practice can be very easily confused with ‘creating computational abstraction (PS5)’. The difference between the two practices can be clear to see when considering the textbook definitions. When looking at practical examples in real modules, though, deciding between the practices can be a difficult decision.

Programming and Algorithms (PS2)

Definition

The writing of a computer code or an algorithm, either a new program / algorithm or modifying an existing program / algorithm. Some examples of how a student would demonstrate this practice would be:

- Expressing the mathematical formulas governing climate change, climate change data inputs and outputs to be used to solve the problem in a way that the computer can understand.
- Can be simpler to use languages like Python or more intensive languages like C++.
- Writing an algorithm to show the thought process behind making a decision about what solution to use for the given problem.

What is New for Computational Thinking with This Practice?

The use of a computer for programming is obvious and this practice means using conditional logic, iterative logic, recursions, and creating abstractions such as subroutines and data structures.

Example of This Practice's Use

The following 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 activity can be found at the end of the second lesson of the four lesson module. The activity sees the students programming their Arduino to act as an earthquake alarm.

4) Enter the following Arduino code into the IDE, upload it to Arduino, and check if it works by shaking the alarm.

파일 편집 스케치 툴 도움말

sketch_sep18a §

```
void setup() {
  Serial.begin(9600);
  pinMode(3,INPUT);
  pinMode(4,OUTPUT);
}

void loop() {
  int earthquake = digitalRead(3);
  Serial.println(earthquake);

  if(earthquake==0) digitalWrite(4,HIGH);
  else digitalWrite(4,LOW);

  delay(2000);
}
```

This activity is considered to be 'programming and algorithms (PS2)' as the students are inputting the computer code to tell the Arduino how to act.

An Example of Activity That Could Be Confused for This Practice

The following example is from an engineering module where the students are learning about airplanes. The module starts with the students learning about the rules that govern what items are prohibited when travelling on an airplane and finishes with the students learning about the forces that act on an airplane wing that allows for it to fly.

[Activity 3] Today and Tomorrow at Airport Checkpoint

1. Consider aviation safety, but minimize passenger inconvenience! (Locating the airport's checkpoint)

Metal detectors can detect weapons such as pistols. But not all metal products can be banned to prevent weapons. Design an airport checkpoint that can effectively protect aviation safety while minimizing passenger discomfort. Considering the “places you'll need to go through a plane,” you've learned earlier, let's divide the airport search into several roles and arrange them along the passenger's route.

☞

☞

The example shows an activity that can be found at the end of the first lesson of the module. In the activity the students are designing an airport security checkpoint. This could be confused as ‘programming and algorithms (PS2)’ as the laying out the checkpoint process is very similar to making an algorithm of the process. While making a draft version of the checkpoint in algorithm form, might be a step the students take, the activity does not say that the students should do that. The activity should therefore be considered to be ‘designing computational models (MS4)’.

Where This Practice is Commonly Found in Lessons and Modules

This practice is often found towards the end of lessons and modules. This is because students will have gone through the lesson learning about the concept / phenomena before being able to make a program or algorithm for the process to find a solution.

Final Thoughts

This is not a commonly found practice. This might be due to the fact that teachers and course creators consider programming to be too difficult for middle school level. This is not necessarily true and it is possible to have students of all ages do some programming through various platforms, such as, Scratch, Alice, or Blockly.

Choosing Effective Computational Tools (PS3)

Definition

Choosing a computational tool based on its range of use, adaptability, and whether the tool fits well with the planned data inputs and wanted outputs. Assessing the pros and cons of some computational tools to make the right choice for the requirements. Some examples of how a student would demonstrate this practice would be:

- During an investigation of climate change the students might want to investigate the temperature. Which tool will fit the requirements? Will a mercury thermometer be best or does the student require a much more accurate laser thermometer? Will the digital laser thermometer be a better choice as it can automatically export the data to a computer?

What is New for Computational Thinking with This Practice?

CT expands the range of factors the student must consider. The ability of some tools to automate the process must be factored into any decision the student makes about which tool is the best for them.

Example of This Practice's Use

The following example is from an engineering module that has students studying about environmental destruction and animal extinction. The students then consider how technology, especially drones, can be used to survey and restore ecosystems.

The activity can be found at the end of the first lesson but is the start of the design process of the students making their own ecological model. The students are considering the best materials for modelling the different aspects of their model. As the students are making choices about which materials would be best the practice they are demonstrating is, 'choosing effective computational tools (PS3)'.

4-3 Explore ecology around us

Think about the eco-environment model you want to express using the materials. let's see.

Material to be picked up (excluding disposables): Carrara, Blue Moss, Colored Paper, Tinfoil, Anvil, Cellophane Paper

Three ingredients from the individual or group:

The element you want to create	Expression method	Remarks (material)

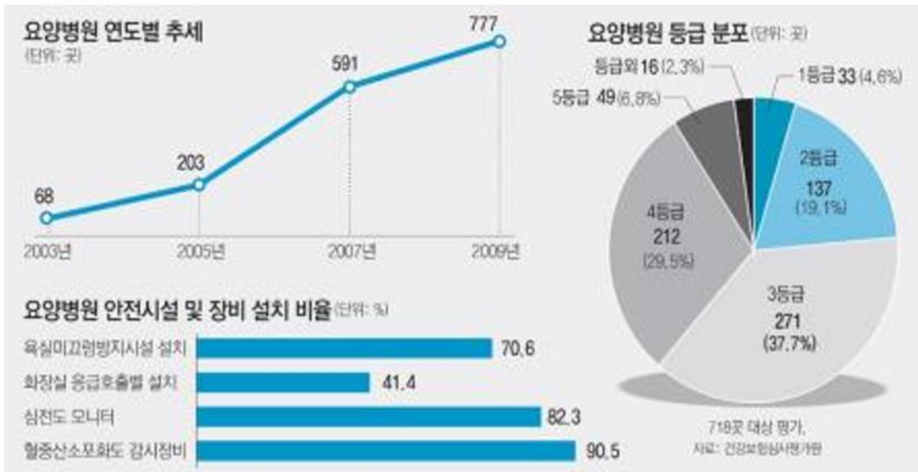
An Example of Activity That Could Be Confused for This Practice

The example below 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.

The activity shown in the example can be found towards the end of the second lesson of the module and is an activity that has the student considering how to report the results of a survey their conducted to find the issues that elderly people face in their daily lives.

The activity could be confused for 'choosing effective computational tools (PS3)' as the students are discussing the pros and cons of the different types of graph. The debate concerns whether the graph is a tool or a model. The researcher considers the graphs to be a model as they are reporting the results rather than a tool to collect the results. Therefore, this activity is considered to be ‘assessing computational models (MS3)’.

The following is an example of using various graphs. What are the advantages of each graph? Connect the lines to see what kind of fact you want to use.



Where This Practice is Commonly Found in Lessons and Modules

This practice can be found anywhere in the lessons and modules. The practice is often found along with the ‘designing computational models (MS4)’ practice as the decision as to which tools best fits the requirements in part of the design process.

Final Thoughts

It is easy to confuse this practice with ‘assessing computational models (MS3)’. There is often some confusion as to what constitutes a model and what constitutes a tool.

Assessing Different Approaches / Solutions to a Problem (PS4)

Definition

When faced with a choice between two models that will both provide the correct results other aspects like cost, time, durability, extendibility, reusability, and flexibility should be taken into account. Some examples of how a student would demonstrate this practice would be:

- The student want to use a digital thermometer but it very expensive and so the student has to think again about which tool to use.

- The students considering the solution that their classmates have developed to solve the same problem.

What is New for Computational Thinking with This Practice?

This is another practice that is not fundamental changed by CT. The student is assessing the approach or solution, whether that is computational in nature or analog.

Example of This Practice's Use

The following example is from an engineering module where the students are learning all about safety in different aspects of life. The students will also build their own safety automata for a given situation.

This is midway through the final lesson of the module. This module is about exhibition hall, i.e. the students have to display and show their work to other students. The students have been designing a safety appliance.

In this activity the students have to look at the work of other students to decide which group was best in the seven different safety zones, life safety, traffic safety, drugs and cyber addiction, violence and personal safety, disaster safety, occupational safety, and first aid. This is considered PS4 as the students have to assess the different approaches and solutions developed by the other groups.

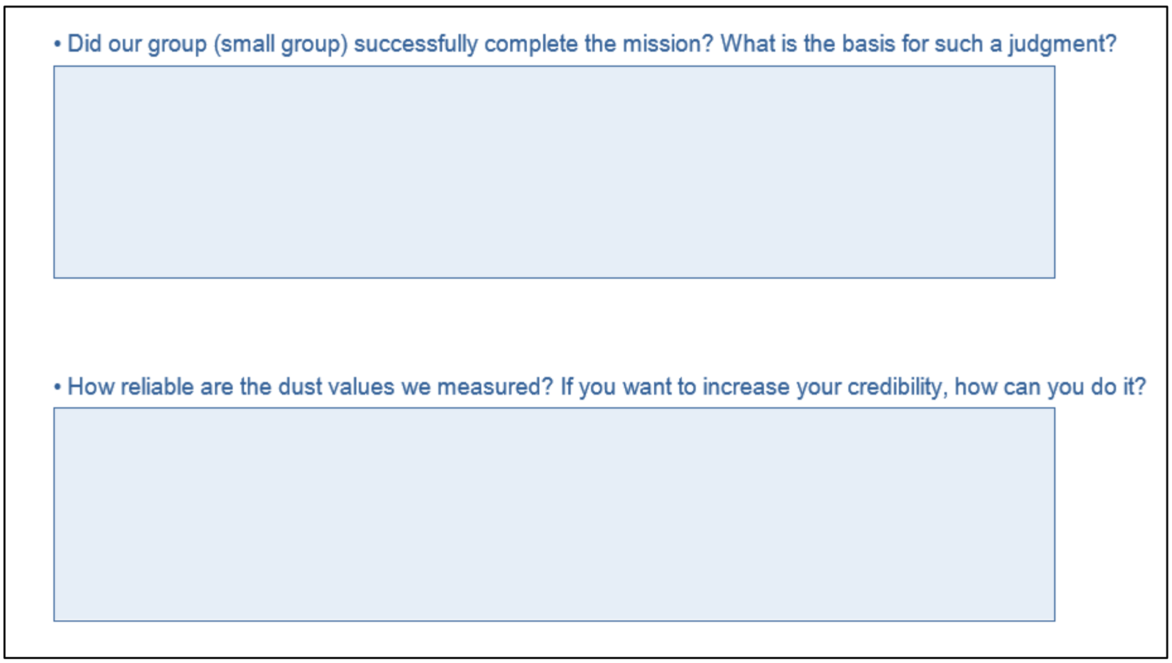
<View contents summary>

7 safety zones	What safety incident did you represent?	What is the best practice?
Life safety		
Traffic safety		
Drugs, cyber addiction		
Violence and Personal Safety		
Disaster safety		
Occupational Safety		
first aid		

An Example of Activity That Could Be Confused for This Practice

The following example is from an engineering module of the students studying about fine dust. The students study about the nature of fine dust and the changes in fine dust concentration in different areas of Korea. They then learn about different methods of reducing the amount of fine dust caused by cooking. The activity shown below comes at the end of the second lesson of the module and is the final activity in a series of activities where the students are measuring the fine dust concentration in their local area and then analyzing the results.

It could be confused for 'assessing different approaches / solutions to a problem (PS4)' as the question whether there results meet the requirements and if the results are accurate. However, as the students are considering their own groups experiment rather the experiment of another group this practice should be considered as 'assessing computational models (MS3)'.



Where This Practice is Commonly Found in Lessons and Modules

This practice is very often found at the end of modules as an 'exhibition hall' activity, where the group report on their work to the other groups in the class.

Final Thoughts

It is easy to confuse this practice with 'assessing computational models (MS3)'. The difference is that this practice should be the assessment of other people's approaches / solutions.

Creating Computational Abstractions (PS5)

Definition

Bring the most important aspects of a phenomena to the front while relegating the less important aspects to the background. Abstractions are important for solving multiple problems that are structurally similar but differ in the details. Some examples of how a student would demonstrate this practice would be:

- When attempting to investigate a problem like climate change there are too many variables to investigate them all. The student needs to decide which variables to concentrate on and which can be safely neglected.

What is New for Computational Thinking with This Practice?

The fundamental nature of making abstractions has not changed with CT. What has changed is what abstractions the student might decide to make now that the model is computational in nature.

Example of This Practice's Use

The follow example is from a science module where the students are learning about autonomous self-driving cars. The students learn about the different safety aspect of the cars and the moral and ethical decisions that might need to be made.

This is at the start of the module and is part of the students being introduced to the topic of autonomous cars. In this activity the students have to think about the dangers the Smombie will face as they walk around without looking around. The students are deciding how to design an autonomous car to replicate the functions of the organs of the body. This is considered to be PS5 as the students have to simplify the functions of the organs.

How can an autonomous car drive itself?

Do you know the coined term “Smombie”? It is a compound word of smartphone and zombie. It means a person walking on the road while watching a smartphone. 'Smombie' is also called a time bomb because it walks slowly and doesn't look around. Why?

What should you do if you find a sinkhole in front of your eyes while walking on the road with a friend? Naturally, it will be avoided with safety in mind. How do our bodies collect various information about road conditions, such as obstacles, when we walk? How will the information we collect be determined and acted upon?

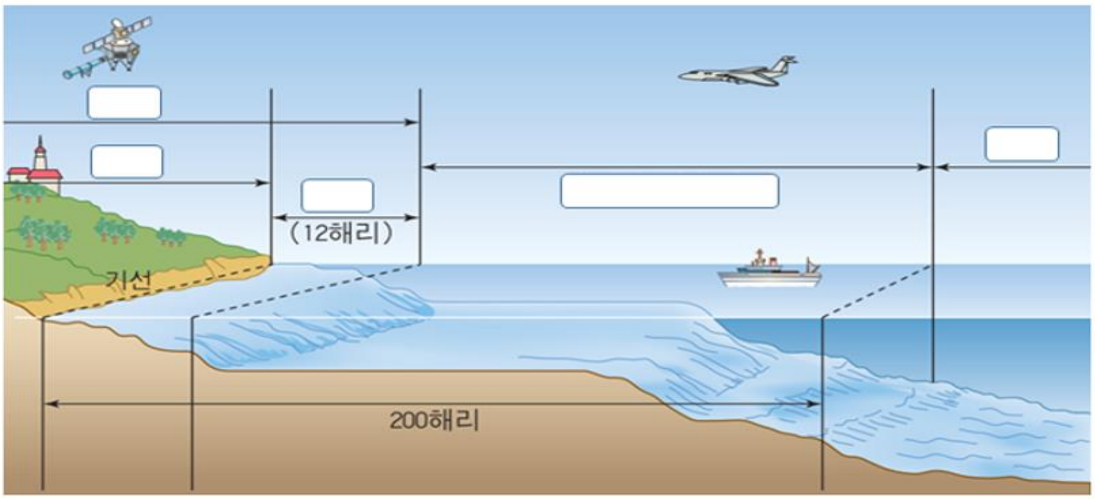
Considering the organs of our bodies, let's design and implement an autonomous car to drive on its own.

An Example of Activity That Could Be Confused for This Practice

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.

The activity is at the start of the third lesson of the module and part of a series of activities that have the students considering the historical and geographical reasons for why Dokdo should be considered part of Korean territory. In this activity the students are considering the factors that relate to the economic value of Dokdo. This activity could be confused for ‘creating computational abstractions (PS5)’ as it might be thought that the students are deciding what the important economic factors are. However, the students are not try to simplify the issue of economic value they are breaking the issue down into its separate factors. Therefore, this activity should be considered to be ‘decomposing problems to allow for a computational solution (PS1)’.

It is clear that Dokdo belongs to the Republic of Korea in terms of its geographical location, and in terms of its territories. Think about factors that are deeply related to Dokdo's economic value and fill in the blanks.



Where This Practice is Commonly Found in Lessons and Modules

This practice is very often found at the start of lesson and modules. It is often used as a way to introduce the concept / phenomena to students and get them thinking about what are the important aspects of a problem and what are the less important aspects.

Final Thoughts

This practice can be very easily confused with 'decomposing problems to allow for a computational solution (PS1)'. The difference between the two practices can be clear to see when considering the textbook definitions. When looking at practical examples in real modules, though, deciding between the practices can be a difficult decision.

Troubleshooting and Debugging (PS6)

Definition

Methodically finding, isolating, duplicating, and rectifying computational tools that are giving unpredicted results. Some examples of how a student would demonstrate this practice would be:

- Inspecting the computational tools to understand why the results produce are not matching what was expected. For example, after the student chooses the digital laser thermometer, but one of the thermometers is giving a very high temperature reading. The student needs to troubleshoot why. Is it an electrical fault or an error in the software? Or is the strange result due to human error in that the student is misusing the equipment?
- Checking the code the students have programmed to find the mistake that is causing it to calculate the incorrect result.

What is New for Computational Thinking with This Practice?

This practice has not fundamental changed with CT, but finding the problem with a computational model is very different to solving a mechanical issue with a physical model.

Example of This Practice's Use

The following example is from an engineering module where the students are learning all about safety in different aspects of life. The students will also build their own safety automata for a given situation.

This is one of the steps involved in the creation of a safety automata. The students are given some materials and asked to choose a safety accident for a type of movement. In this activity the students are asked to think about problems that arose during the production process and how the students went about solving the issues. This is considered to be the PS6 practice as the students had to find a solution to any problems that occurred. This is called troubleshooting.

생각 모으기 Collect thoughts

2. After completing an automata representing safety accidents, think about what went wrong during the production process and summarize what the problem was and how it was solved.

What was the problem?	How did you solve it?

An Example of Activity That Could Be Confused for This Practice

4 For a safer ride!

What's a good idea for overcoming the reality barriers faced by autonomous cars?

In order for autonomous cars to run on the roads of reality, there are many mountains to overcome. Citizen's consensus on the safety of autonomous vehicles, complementing laws and institutions. What ideas do you need to make your self-driving car improve with a safer ride? Use the following creative design activities to show off your quirky and weird imagination.

The above example is from a science module where the students are learning about autonomous self-driving cars. The students learn about the different safety aspect of the cars and the moral and ethical decisions that might need to be made.

The example can be found towards the end of the third and final lesson of the module. In the example the students are contemplating ways to make self-driving autonomous car safer on the roads. This activity maybe confused for 'troubleshooting and debugging (PS6)' as the students are finding ways to improve the safety of the cars. This CT practice is about fixing a model / tools code that isn't working as intended. This example, however, is about things of new ways to make the car safer in given situations. Therefore, it is the 'designing computational models (MS4)' practice.

Where This Practice is Commonly Found in Lessons and Modules

This practice is found at the end of activities where the students are preforming an experiment or using a model to observe a concept / phenomena

Final Thoughts

During the researcher analysis of STEAM modules this was a very rarely found practice. However, this probably due to it being an unmentioned step in every experiment activity. Problems and issues that need troubleshooting are very common in experiments and it may just be an assumed part of running the experiment and so is actually a very common practice.