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Elementary Preservice Teacher Coursework Design for Developing Science and Mathematics Computational Thinking Practices

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This paper describes disciplinary computational thinking (CT) interventions within mathematics and science methods courses, an instructional technology course, and a practicum placement for elementary preservice teachers (PSTs). The population included two cohorts of elementary PSTs from fall 2018 (n = 9) and fall 2019 (n = 12). Curricular interventions included opportunities for PSTs to practice using, teaching, and reflecting upon disciplinary CT activities with educational robotics, 3D printing, and maker-centered tasks. Results indicate statistically significant increases in self-perceptions of technology, pedagogy, and content knowledge (TPACK), Personal Science Teaching Efficacy as measured by the STEBI instrument, and CT-efficacy for teaching as a result of participation in coursework. The PSTs were also able to describe specific ways they could use CT tools and practices for teaching elementary content and logically apply aspects of TPACK, Substitution Augmentation Modification Redefinition, and the CT in Mathematics and Science Taxonomy practices to their instruction (Weintrop et al., 2016). Recommendations include a progression of activities within courses that can serve as a model for other teacher educators in preparing PSTs to use disciplinary CT.

The need is growing to prepare students to enter the workforce with skills in science, technology, engineering, and mathematics (STEM) and, in particular, computer science (CS) (Bureau of Labor Statistics, 2018; Computer Science Teachers Association [CSTA], 2016). Computer and information technology occupations are expected to grow 12% from 2018 to 2028, which is at a much faster rate than the average for all occupations. Society and work environments are changing rapidly due to the innovations of the Fourth Industrial Revolution, characterized by the use of emerging technologies such as artificial intelligence, biotechnology, the internet of things, and autonomous vehicles, together with how humans interact with these technologies.

The use of technologies such as voice-activated assistants, facial ID recognition, and digital health-care sensors are “blurring the lines between the physical, digital, and biological spheres” (Schwab & Davis, 2018). Marr (2019) suggested that schools had several challenges to prepare students for the Fourth Industrial Revolution, including improving STEM education, developing the human potential to partner with machines rather than compete with them, adapting to lifelong learning models, facilitating student inquiry, and encouraging collaboration and creativity with the use of makerspaces.

One approach to preparing citizens for much-needed critical thinking and problem-solving skills is to teach computational thinking (CT) skills within K-12 schools (Hunsaker, 2018). Yadav et al. (2016) stated that many constraints exist to teaching CT within the context of a standalone CS class within K-12 schools. Preparing new teachers to integrate CT within specific disciplines is, therefore, important.

Embedding CT practices within mathematics and science courses benefits students both academically and economically by providing opportunities to prepare students better as creative and critical thinkers and to meet the future needs of the job market (Grover & Pea, 2013; Hunsaker, 2018). Incorporating disciplinary specific CT instruction, such as solving community problems or completing STEM-related projects, is likely to help students see the real-world applications of CT (Ching et al., 2018).

Despite the benefits of maker-centered instruction, which includes the use of CT practices, there are a limited number of teacher preparation programs in the United States that provide opportunities to develop these skills (Mason & Rich, 2019; Rodriguez et al., 2019; Yadav et al., 2017). Within this context the current project was designed to address the need to prepare STEM-literate preservice teachers (PSTs) who possess CT skills. Ultimately, the goal was to enable these new teachers to prepare all of their students at an early age, regardless of ethnicity, gender, and socioeconomic status, for a workforce with skills in STEM, particularly in CT skills and engineering.

As part of the undergraduate curriculum, the primary investigator teaches science, mathematics, and instructional technology methods courses to elementary PSTs enrolled in a cohort program. This teaching assignment provided an opportunity to prepare future teachers to embed CT practices within mathematics and science as they engaged in CT activities throughout the semester aligned with the maker education movement and CS initiatives.

Research questions guiding this study were as follows:

How do comprehensive mathematics and science CT interventions (educational robotics, 3D printing, and maker-centered learning) impact PSTs’:

- self-perceptions of technological pedagogical content knowledge?
- science teaching efficacy beliefs?

- self-efficacy for and use of CT within mathematics and science instruction?

The rationale for these research questions is illustrated further in the following literature review by documented elementary PST misconceptions of the meaning of CT, as well as elementary PSTs' lack of self-efficacy for teaching science and associated STEM fields. The motivation for redesigning science, mathematics, and instructional technology courses was to provide opportunities for PSTs to practice using disciplinary-specific CT skills, teach a mathematics, science, or STEM lesson that integrates CT skills, and reflect upon how these opportunities impacted their perceptions of TPACK and self-efficacy for these disciplines over the course of a semester.

PSTs often uptake and implement practices in which they have personal experience; therefore, their experiences using technology and CT practices in education courses critically impacts their use as they transition to their own classrooms (Rodriguez et al., 2019; Yuan et al., 2019). The literature review also illustrates that developing PST pedagogical content knowledge for disciplinary-specific CT is a relatively emergent field of research and the need exists to contribute to this literature base.

Literature Review

What Is Computational Thinking?

CT is characterized by problem solving, modeling, data mining, networking, algorithmic reasoning, programming, designing solutions, communicating thoughts in a creative, organized way, and debugging (CSTA, 2016; Sneider et al., 2014). The K-12 CS Framework (CSTA, 2016) has outlined clear relationships between CS, science, engineering, and mathematical practices embedded within the *Next Generation Science Standards* (NGSS; NRC, 2012) and *Common Core State Math Standards* (CCSMS; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010). Weintrop et al. (2016) developed a CT in mathematics and science practices taxonomy that includes four major categories, including Data Practices, Modeling and Simulation Practices, Computational Problem-Solving Practices, and Systems Thinking Practices.

While CS concepts and skills are outlined clearly in current standards, they are new to students, teachers, and other stakeholders who often incorrectly label basic computer literacy activities such as creating documents and searching the internet as CT skills (CSTA, 2016, International Society for Technology in Education, 2018). Sands et al. (2018) surveyed teachers and found that many lacked an understanding of the core components of CT and lacked awareness of how these skills can be implemented in classrooms.

CT and Elementary Preservice Teachers

Elementary teachers often lack knowledge and self-confidence in STEM fields as well as CS and CT (Kaya et al., 2018; Novak & Wisdom, 2018; van

Aalderen-Smeets & Walma van der Molen, 2015). Surveys of PSTs indicate that they have misconceptions regarding the meaning of CT and often equate CT as using technology rather than as a problem-solving process (Cabrera, 2019; Yadav et al., 2011). Sands et al. (2018) claimed the need to prepare PSTs in CT practices regardless of their respective academic discipline. Yadav et al. (2017) claimed that teacher educators can help PSTs develop CT skills by redesigning educational technology courses to introduce the core ideas of CT and use methods courses to help develop PSTs' understanding of CT within the context of the discipline. Mouza et al. (2017) noted that PST graduates should be prepared to infuse CT skills into the curriculum from primary grades through secondary education given the importance of CT in the 21st century.

Mason and Rich (2019) conducted a literature review of current elementary, K-6, preservice, and in-service teacher research from 2008-2018 focused on attitudes, self-efficacy, or knowledge to teach computing, coding, or CT. They identified and analyzed 21 studies,12 with PSTs using elements of effective PST preparation based on recommendations from Ertmer and Ottenbreit-Leftwich (2010). Recommendations for teacher preparation programs are to provide opportunities for candidates to observe, practice and reflect as a means to increase content, technological, and pedagogical knowledge and improve attitudes, self-efficacy, and beliefs. Findings included that this type of teacher training was emergent with the majority of these studies published from 2017-2018. The main focus has been to improve content knowledge and attitudes toward CS, with limited emphasis on developing pedagogical knowledge. Implications for teacher educators are that PST training should include modeling and opportunities to practice, teach, and reflect upon CS activities in authentic contexts.

Several recent studies since the Mason and Rich (2019) literature review have looked at ways to influence elementary PST confidence and use of CS and CT and maker-centered learning. Kaya et al. (2019) described how a 3-week CT intervention focused on code.org (https://code.org/) curriculum, robotics, and gaming in an elementary PST course positively impacted self-efficacy, interest, and confidence.

McGinnis et al. (2020) described a three-session CT module within a science methods course, including an introduction to CT and the NGSS, challenges through robotics, and CT integration through citizen science. The semester culminated with teaching a lesson integrating CT as part of PST internship placements. They found that although PSTs were receptive to using CT and found it beneficial to students, future research should support PSTs in comparing and contrasting educational technology, scientific inquiry, and CT. Major implications of their study included how PSTs could benefit from discussing how to integrate CT without technology and providing examples of lessons that integrate CT at the elementary level. Yuan et al. (2019) explored how elementary PSTs designed lesson plans integrating robotics after participation in a robotics module in an education course. Implications for teacher educators included providing PSTs opportunities for productive struggle within a robotics learning environment and content-specific training and modeling to help PSTs determine how to integrate robotics within and across disciplines.

Based upon the need to develop PSTs' pedagogical knowledge within the context of disciplinary CT, often with the use of technological tools, the TPACK Framework and Substitution Augmentation Modification Redefinition (SAMR) models served as guiding technological frameworks for this project. Both the TPACK framework and the SAMR model were introduced to PSTs early within the semester of the interventions and referred to throughout the semester.

TPACK Framework and SAMR Model

As described by Mishra and Koehler (2006) the TPACK framework explores how technology is integrated with teaching through the overlapping constructs of technology, content, and pedagogy. The TPACK framework builds on the work of Shulman (1986) and is based upon the need for teachers to build subject-specific pedagogical content knowledge. The proper use of TPACK emphasizes the context-specific nature of incorporating digital technology with expert knowledge of best practices within specific disciplines (Bull et al., 2019; Koehler et al., 2013).

The SAMR model is a framework used to assess and evaluate digital technology use in the classroom (Puentedura, 2010). The model includes four levels divided into two sections as a means to promote teacher reflection and technology integration. First, the Enhancement section consists of the Substitution (technology acts as a tool substitute) and Augmentation (adds a functional change) levels. Next, the Transformation section consists of the Modification (task redesign) and Redefinition (creation of new tasks) levels. The challenge is for teachers to develop tasks within the Transformation section that lead to different learning from students, which can include greater student engagement and, ultimately, increased student achievement and learning.

Cohort Design

The population included two cohorts of elementary education PSTs from fall 2018 (n = 9) and fall 2019 (n = 12). All students were first semester juniors in a 4-year elementary education licensure program. Each cohort was enrolled in four courses with the primary investigator including science methods (3 credit hours), mathematics methods (3 credit hours), instructional technology (3 credit hours), and a 60-hour practicum placement that allowed an opportunity for meaningful STEM and CT integration as outlined in Figure 1.

PSTs were encouraged to develop a maker-mindset throughout the semester as they developed CT practices and worked through successes and failures, particularly with programming and 3D printing (Martin, 2015). As they actively designed and built digital or physical objects through trial and error and perseverance, they were asked to focus on developing a growth mindset (Dweck, 2008).

Figure 1 Map of CT Curricular Interventions Fall 2018/2019 Cohorts

Map of CT Curricular Interventions Fall 2018/2019 cohorts

	Mathematics Methods	Science Methods	Instructional Technology	Grades 3-5 Practicum Placement
Sept.	• Introduction to Mindset (Growth & Fixed) Jo Boaler's course	• Bottle Rockets module • Makerspace Article and reflection • Circuits module • STEM BOSS conference (2018 only)	• Field trip to local middle school makerspace • Hour of Code, Scratch, PHET simulation (Read Sneider & Weintrop articles) • TPACK & SAMR Models Introduction	STEM Night 1
Oct.	Introduce common lesson plan format used for each course	• Field trip to Oak Ridge National Laboratory (2019 only)	• Robotics and Makerspace Inquiries • 3D Printing & City X	STEM Night 2 & 3
Nov.	Tennessee Science & Mathematics Teachers Association Joint Conference Attendance and Presentation (2019 only)		Planning for CT Lesson and In-class practice	STEM Night 4 (2019 only)
Dec.				Co-teach Disciplinary CT-based Robotics/Makerspace Lesson

During the science methods course, PSTs developed investigations and modules that focused on three-dimensional instruction and assessment focused on real-world phenomena incorporating disciplinary core ideas, science and engineering practices, and crosscutting concepts. One of their first tasks was an engineering design challenge of creating and launching a bottle rocket as a team and collecting and analyzing data using a spreadsheet (amount of water added, air pressure added in PSI, time in air, and altitude of flight with an altimeter). This particular task provided an introduction to specific CT practices in the form of collecting, manipulating, analyzing and visualizing data and the use of systems thinking practices by understanding the relationships within a system (bottle rocket, launcher, and materials) and communicating information about the system (Weintrop et al., 2016). One module in the mathematics methods course was an introduction to growth and fixed mindset (Dweck, 2006), which PSTs were encouraged to apply throughout the entire semester as well as emphasize in their classroom practicum placements.

The instructional technology course served as a platform to prepare the PSTs to develop and apply disciplinary-specific CT activities and lessons that addressed both three-dimensional science instruction and mathematical practices. They were introduced to the TPACK Framework and SAMR Model. The fall 2019 cohort was asked to apply an understanding of these models as part of the rationale for a culminating lesson that they team-taught to elementary students.

CT Interventions/Curricular Modules

Collaboration With Local School

The primary investigator reached out to a local grades 5-8 middle school in which a number of the PSTs would be placed for their practicum in fifth-grade science or mathematics. This particular school also had an active makerspace in its library, and arrangements were made to have the fifth-grade students introduce the makerspace tools to the PSTs.

We took one 3-hour class and used it for a field trip to the middle school, and three different fifth-grade classes (1-hour each) taught about the tools in stations. Each PST spent 10-15 minutes with a small group of expert fifth graders, in which they were taught some basics about the tool and wrote reflective notes. The stations included 3-D pens, Little Bits, Snap Circuits, MakeyMakey, Osmo, Green Screen, Stop Motion/Lego Wall, Bloxels, Wonder Workshop's Dash, Make Do Construction, and Ozobots. A goal of this collaborative effort was to ask the PSTs to plan lessons that could be used within their practicum placements that integrated at least one of the makerspace tools along with incorporating disciplinary CT within science and mathematics. These lessons, in turn, could serve as models for in-service teachers as ways in which they could teach content and incorporate CT and makerspace tools within their classrooms.

The field trip to the makerspace was followed closely with an assigned reading from the March 2018 issue of the National Science Teacher Association's *Science and Children* that had a central focus on the maker movement. Each PST read, "Making Sense of Makerspaces" (Froschauer, 2018) and was assigned one of four articles: "School Maker Faires" (Harlow & Hansen, 2018), "3D Print Stop Printing" (Wright et al., 2018), "Mars Mission Specialist" (Burton et al., 2018), or "Plastic Pollution to Solution"(Kitagawa et al., 2018). PSTs who read the same article contributed main ideas and reflections to a shared online concept map that was used to describe the article to the rest of the class.

Hour of Code and Reading

Students completed an hour of code using a drag-and-drop coding format with Code.org studio's Classic Maze featuring Angry Birds, https://studio.code.org/hoc/1. This hour of code has 20 modules, or scenarios, with video segments that explain different CS and CT concepts (code, debugging, algorithm, repeat loops, repeat until, and if-else statements). In addition, they were asked to complete a brief internet search for ways teachers use coding effectively with elementary students.

After completing the basic hour of code they read "Exploring the Science Framework and the NGSS: Computational Thinking in Elementary School Classrooms" (Sneider et al., 2014). They explored a PHET simulation (https://phet.colorado.edu/) and one of the 11 Scratch Tutorials found at https://scratch.mit.edu/tips. The PSTs also read portions of "Defining Computational Thinking for Mathematics and Science Classrooms" (Weintrop et al., 2016), focused on describing the four CT practices in the article. We discussed as a class that, even though the taxonomy focuses on the use of computational tools, CT also addresses unplugged activities or modeling and thinking practices that do not include computers or technology.

Robotics and Makerspace Inquiries

The inquiry required the PSTs to work with two different tools, the majority of which were introduced briefly in stations with the local middle school. The ultimate goal was to take the PSTs beyond basic use of each tool for standalone programming toward integration of the tool with engineering design and the core ideas of mathematics or life, physical, or earth and space science at the K-5 level.

PSTs either worked individually or with a small group to select one lesson plan using the tool with guidance from the primary investigator. They were asked to carry out the lesson plan and complete the steps as K-5 students would by documenting their work using written reflection, pictures, screenshots of programming, and annotated sketches. Finally, they reflected on how the tool could be used in the elementary classroom. See Appendix A for sample student artifacts.

The robotics inquiries used kits that featured a drag-and-drop programming interface allowing a focus on computational concepts instead of the syntax of a specific programming language (Ching et al., 2018; Nash, 2017). These kits made the process of learning abstract CT concepts more tangible, as PTSs were able to interact with, observe, and troubleshoot the robot in action. The online curriculum provided with Wonder Workshop's Dash & Dot (https://www.makewonder.com/classroom/curriculum-2/), Sphero (https://edu.sphero.com/), Lego Education WeDo 2.0 (https://education.lego.com/en-us/lessons), and Ozobot Evo (https://ozobot.com/educate/lessons) provided real-world applications to develop CT as part of STEM concepts including science and engineering practices based real-world applications. These inquiries incorporated both physical building such as using the Lego bricks or creating mazes and digital building through programming.

3D Printing and City X

Our classroom included three DaVinci Jr. 1.0 Wireless 3D printers from XYZ printing, which are low-cost machines that are easy to set up, troubleshoot, and operate. Three-dimensional printing comes with specialized vocabulary and skills, so the PSTs needed to learn the basics, including the file type supported by the printer (STL), 3D printer hardware basics (X, Y, and Z axes, extruder, print bed, how to load and unload filament, etc.) and when they should choose to add supports or a raft to their print. To begin their exposure to 3D printing, each student was asked to locate one object from Thingiverse (https://www.thingiverse.com/) to print.

The PSTs used a free online program called Tinkercad (https://www.tinkercad.com/) that allows the user to create designs for objects that can be downloaded as STL files and printed on a 3D printer (Autodesk Inc., 2019). They used Tinkercad as part of the City X project, which uses the design process for solving problems with 3D printing from Stanford d.school (https://dschool.stanford.edu/).

City X (http://www.cityxproject.com/) was developed for children 8-12 years old and challenges students to solve the problems of humans who have traveled to live on an alien planet. The PSTs worked in teams to solve social problems related to environment, food, safety, communication, health, energy, education and transportation as presented by citizens of City X. They used the design process to empathize, define, ideate, prototype, test, and share while using an inventor's workbook, sketching and annotating, designing with playdough, and calculating dimensions prior to designing their object using Tinkercad. Each PST was asked to design a part of the solution for their selected citizen to ensure that they each had a part in creating a prototype. The PSTs also spent time troubleshooting and reprinting their objects as needed to find the best fit for their collective design. See Appendix B for an example project from each cohort.

Participating in the City X project and designing their prototype in Tinkercad allowed the PSTs to experience directly and develop CT practices, including decomposing a problem presented by a citizen of City X into manageable parts, using abstraction by reducing unnecessary details, and using algorithmic thinking by developing a written plan and design with playdough that provided a step-by-step guide for creating the model using Tinkercad. In addition, the use of Tinkercad to create the models allowed for investigating a complex system as a whole and understanding the relationships within a system (Weintrop et al., 2016). Each PST designed several iterations of a prototype through troubleshooting a portion of the solution for each selected citizen of City X.

STEM Nights

Each PST was required to participate in two STEM nights held at local schools and were responsible for leading at least two stations as part of a team as seen in Figure 2. The in-service teachers at each school also hosted several of their own stations and invited community members to host stations as well. With the number of stations available for children to choose from, the time allotted to visit each station ranged between 5 to 15 minutes. The events offered at each STEM night progressed as PST knowledge of the tools grew throughout the semester.

Lesson Plans During Practicum Placements

The final activity for each cohort was to plan and team teach a lesson that addressed disciplinary CT in mathematics or science for grades 3-5 students in their practicum placements in early December. This activity provided an important extension beyond what was possible in the STEM nights, which only touched the surface of using CT for subject-specific instruction. Each team was able to teach the lesson to at least two groups of students.

Figure 2 STEM Night Stations

STEM Night Stations

Fall 2018 STEM Nights	Fall 2019 Nights
STEM Night #1 • Bottle Rocket Launches • Dash Robots with Go! app • Sphero Robots (remote controlled) • Code & Go Mouse • Quiver Color AR App	STEM Night #1 • Bottle Rocket Launches • Carbon Copy Creations (Legos and giving directions) https://slideplayer.com/slide/8154975/ • Assembly line with pens – constructing & deconstructing a pen (Reverse engineering)
STEM Night #2 – Spooky STEM Night • Monster Mask – conductive tape, bulb, & battery https://www.nisenet.org/catalog/monster-mask • Conductive Play Dough (Dough Monsters) https://www.nisenet.org/catalog/dough-creature • Scribble Bot https://www.nisenet.org/catalog/scribble-bot • Slime station	STEM Night #2 – Spooky STEM Night • 3D Pen bubble wands https://learn.the3doodler.com/lessons/primary-build-a-better-bubble/ • Ozobot Evo drawing • Dash & Sphero – Go app • Code & Go Mouse & Beebot Monster Mashup bundle https://www.teacherspayteachers.com/Product/Bee-Bot-Code-Go-Mouse-Dash-Sphero-Robot-Coding-Activities-Monster-Mashup-4371101
STEM Night #3 – STEM at the Movies • Marvel Movies – Ozobots with toppers; coding on paper with markers • Green Screen – magic behind the movies • Unplugged coding with Superheroes – coding on gameboard https://littlebinsforlittlehands.com/superhero-computer-coding-game-without-a-computer/ • Dash & Dot Room – Battle Bots with skewers and balloons • Escape Room – QR codes with movie trivia	STEM Night #3 – High School (for young children in community) • 3D Pen Bubble wands • Code & Go Mouse Able to see vendors that promoted STEM careers, 3D printing, Mechanics class (programming and 3d printing involved in a rural high school); ZSpace lab STEM Night #4 • Dash – sketch kit, launcher accessory & maze; All with Blockly App • Ozobot Evo drawing

PSTs used lessons adapted from those found online to incorporate literacy in the form of asking students to read informational texts and write about what they had learned. The fall 2018 lesson plan template and reflection template came from the UTeach Maker Lesson Planning Guide and summary (https://maker.uteach.utexas.edu/uteach-maker-lesson-bank). The fall 2019 lesson plan template mirrored the format the PSTs used for the rest of their courses, which included references to TPACK, SAMR, and mathematics and science CT practices as research and rationale to support the lesson (Weintrop et al., 2016). See Appendix C for example lesson plans and reflections.

Connection to Industry

In fall 2019 we scheduled a 1-day field trip to the Oak Ridge National Laboratory (ORNL) Manufacturing Demonstration Facility (MDF) which is the "nation's only large-scale open-access facility for rapidly demonstrating early-stage R&D manufacturing technologies and optimizing critical processes" (ORNL, n.d.). The tour enabled the PSTs to see real-world applications and the problem-solving capabilities of engineers using robotics and additive manufacturing situated within their local community. We also had guided tours of the Building Technologies Research and Integration Center and the National Center for Computational Sciences to learn about supercomputers including Titan, Gaia, and Tiny Titan. We concluded our day with a Women in Computing roundtable, in which the PSTs were able to speak with three different women about their experiences working at ORNL. Top take-aways from this roundtable were that more women are needed in their fields and there are ways that teachers can begin working with students to develop CT skills, particularly data analysis skills with spreadsheets.

Big Orange STEM Saturday Conference Attendance

Seven out of the nine fall 2018 cohort attended the Big Orange STEM Saturday conference. The students had a choice of attending two different sessions and a keynote speaker with lunch. The keynote speaker described the use of makerspaces in libraries, and sessions attended by the PSTs included ways to use 3D printers in the classroom, hands-on math focused on designing models and questioning strategies, and using phenomena in NGSS designed lessons and units. These sessions added to the PST awareness of ways tools and strategies emphasized in our methods classes are being used in the classroom.

Tennessee Mathematics and Science Teachers Association Presentation

All 12 PSTs of the fall 2019 cohort and two members of the fall 2018 cohort attended and presented a session at the joint conference of the Tennessee Mathematics and Science Teachers Associations in late November 2019. They received funding from the university to pay for their mileage, lodging, and conference registration fees. They shared lesson plans and activities they were planning to use in their practicum placements that showcased the use of robotics and 3D printers or pens within mathematics and science classes. They set up the equipment and shared hard copies of their lessons with in-service teachers as attendees rotated through the stations in the room.

Methods

This study was designed using a mixed methodology approach of collecting qualitative and quantitative data, because both types of data had equal value for understanding the research questions (as recommended by Buchholtz, 2019; Creswell & Clark, 2017). A convergent parallel design was used to collect both types of data concurrently (Creswell & Clark, 2017). Quantitative data were collected using the TPACK assessment (Schmidt et al., 2009), the Science Teaching Efficacy Belief Instrument (STEBI) assessment (Riggs & Enochs, 1990), and a CT Self-Efficacy assessment compiled from several different sources (Rich et al., 2017; Yadav et al., 2011). Pre and post quantitative data were analyzed using paired sample *t*-tests with the use of a Bonferroni correction to determine the statistical significance of changes.

Narrative analysis was used to discover emergent themes within the qualitative data collected pre- and postparticipation (as advised in Patton, 1990). Participant responses to three open-ended prompts included on the CT Self-Efficacy assessment were analyzed to search for similarities and differences between participant ideas to identify the emergent themes. Select PST reflections for major assignments and the rationale for lesson plans also serve as examples of qualitative data.

Time was provided in class for participants to complete assessments at the beginning of the semester and again at the end of the semester to determine the impact of course interventions upon participant beliefs. The PSTs signed informed consent forms, which stated that they would be expected to complete the pre- and postsurveys and required coursework and that they had the right to decide if the data from their individual surveys and completed coursework could be used for research purposes. All members of each participating cohort agreed to participate in the study. No incentives or compensation were associated with this project for participation. The PSTs did not receive grades for completing the surveys; however, their inquiries, lesson plans, and presentations were graded assignments.

TPACK Survey

The TPACK assessment included 46 Likert-scale items divided into categories taken from the Survey of Preservice Teachers' Knowledge of Teaching and Technology (Schmidt et al., 2009). As recommended by Schmidt et al., each item response was scored with a value of 1 for *strongly disagree* to 5 for *strongly agree*. The participants' responses were averaged over all 46 questions. Additionally, the participants' responses were averaged over each construct. For example, the six questions addressing technology knowledge (TK) were averaged to produce one score.

STEBI

The STEBI was used to measure changes in PSTs' perceived efficacy in teaching science (Riggs & Enochs, 1990). The STEBI contains 13 positively written item statements and 10 negatively written item statements divided among two scales. The response alternatives for each item are in a Likert-style format, including *strongly agree, agree, uncertain, disagree*, and *strongly disagree*. The two scales include the Personal Science Teaching Efficacy Belief Scale (PE - self-efficacy dimension) and Science Teaching Outcome Expectancy Scale (OE -outcome expectancy dimension).

Personal teaching efficacy is the "belief in one's capabilities to organize and execute the courses of action required to produce given attainments, whereas outcome expectancy is a judgment of the likely consequence such performances will produce" (Bandura, 1997, p.3). The participants' responses were averaged as recommended by Riggs and Enochs (1990) for both the PE and OE scales, and a paired sample *t*-test was completed to determine the level of significance of any changes.

CT Assessment

The CT Assessment survey consisted of five Likert-scale items to measure Teaching CT Efficacy focusing primarily on programming skills (see Appendix D). This survey was not prepared in time to use with the fall 2018 cohort; therefore, it was only used with the fall 2019 cohort. Each item response is scored with a value of 1 for *strongly disagree* to 5 for *strongly agree*. The participant's responses were averaged over all five questions, and a paired sample *t*-test was completed to determine the level of significance of any changes. The CT Assessment also included three open-ended questions to determine PST views of what is CT, ways CT can be integrated in the classroom, and ways CT relates to other disciplines and fields with examples.

Findings

TPACK Survey

A paired sample *t*-test was computed for the participant's average responses over all the questions to show a significant change ($p < 0.001$) for both fall 2018 and fall 2019 cohorts. To determine the individual contributions, paired sample *t*-tests were performed on each construct. Once a Bonferroni correction was imposed, five constructs showed a statistically significant increase for the fall 2018 cohort including content knowledge (CK), pedagogical content knowledge (PCK), pedagogical knowledge (PK), technological pedagogical knowledge (TPK), and TPACK. Three constructs, TK, TPK, and TPACK showed a statistically significant increase for the fall 2019 cohort. Table 1 includes the participant average results for pre- and post-TPACK and standard deviation, along with the *p*-value to help illustrate the contribution of each construct to the overall statistical significance for both cohorts.

STEBI

The range of scores for the PE scale was 13 to 65 points. A paired sample *t*-test was computed for the participant's average responses for the PE scale to show a significant change ($p < 0.01$) for both fall 2018 and fall 2019 cohorts. The range of scores for the OE scale was 10 to 50 points. A paired sample *t*-test was computed for the participant's average responses for the OE scale to show no significant change for both fall 2018 and fall 2019 cohorts. Table 2 includes the participant average results for pre and post PE and OE beliefs scores and standard deviation, along with the *p*-value to help illustrate the contribution of each construct to the overall statistical significance for both cohorts.

CT Assessment

A paired sample *t*-test was computed for the participant's average responses over the five Likert-style questions to show a significant change ($p < 0.0001$). To determine the individual contributions, paired sample *t*-tests were performed on each question. Once a Bonferroni correction was imposed, all five questions showed a statistically significant increase. Table 3 includes the participant average results for pre and post Teaching CT Efficacy, which focused on teaching coding and programming skills, and standard deviation, along with the *p*-value.

Table 1 Pre and Post TPACK Assessment Results

TPACK Subscale	Fall 2018 $n = 9$			Fall 2019 $n = 12$		
	Mean	***SD***	***p* value**	**Mean**	***SD***	***p* value**
TK (6 items)						
Pre	3.41	0.33		3.57	0.67	
Post	3.89	0.27	0.0074	4.22	0.51	0.0001***
CK (12 items)						
Pre	3.39	0.14		3.75	0.36	
Post	3.78	0.34	0.0023*	3.87	0.31	0.1330
PK (7 items)						
Pre	3.19	0.47		3.92	0.38	
Post	4.05	0.33	0.0014**	4.22	0.43	0.0136
PCK (4 items)						
Pre	2.97	0.38		3.67	0.33	
Post	3.75	0.33	0.0014*	4.00	0.35	0.0077
TCK (4 items)						
Pre	3.00	0.71		3.40	0.70	
Post	3.86	0.24	0.0088	3.94	0.49	0.0176
TPK (9 items)						
Pre	3.41	0.41		3.89	0.59	
Post	4.22	0.31	0.0014**	4.36	0.42	0.0007**
TPACK (4 items)						
Pre	2.67	0.47		3.50	0.56	
Post	3.81	0.42	0.0002**	4.04	0.39	0.0049*

Note. Pretest and posttest scores are averages between 1 and 5.
*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

Table 2 Science Teaching Efficacy Beliefs

Criteria	**Fall 2018 Participants** $n = 9$			**Fall 2019 Participants** $n = 12$		
	M	***SD***	***p*-Value**	***M***	***SD***	***p*-Value**
Pre-PE	39.9	3.07		45.1	4.50	
Post-PE	44.4	2.91	$^{**}p < 0.01$	49.9	4.84	$^{**}p < 0.01$
Pre-OE	32.6	2.75		34.5	3.89	
Post-OE	32	2.98	$p = 0.283$	34.1	6.37	$p = 0.395$

$^{*}p < 0.05$. $^{**}p < 0.01$.

Table 3 Teaching CT Efficacy Assessment – Likert-Scale Items

Criteria	Pretest		Posttest		*p* value
-	***M***	***SD***	***M***	***SD***	
Teaching CT-E (*5 items*)	2.93	0.66	4.05	0.70	0.000065****
1. I can explain basic programming concepts to children.	2.58	0.95	3.83	0.55	0.000065***
2. I know where to find the resources to help students learn to code.	3.17	0.90	4.17	0.90	0.0020**
3. I can find applications for coding that are relevant for students.	3.42	0.86	4.42	0.49	0.00033**
4. I can integrate coding into lessons I teach.	3.17	0.55	4.17	0.80	0.00094**
5. I can help students debug their code.	2.33	0.75	3.67	1.31	0.0031*

Note. Fall 2019 only; $n = 12$; Pretest and posttest scores are averages between 1 and 5. Individual items 1-5 significance levels include a Bonferroni correction.

*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$. ****$p < 0.0001$.

The CT Assessment also included three open-ended questions to determine PST views of what is CT, ways CT can be integrated in the classroom, and ways CT relates to other disciplines and fields with examples. In most cases, PST responses aligned with the themes used for these prompts by Yadav et al. (2011), so similar themes were used for this study. Table 4 includes a summary of PST pre and post responses for each question.

Table 4 CT Assessment – Open Ended Items

Prompts	**Themes**	**Pre**	**Post**
Views of CT	The process of solving problems	3	3
	The process of solving problems *like* a computer	2	3
	The process of solving problems *with* a computer	1	4
	The use of computers	2	2
	Not sure	3	0
	Other (coding; thinking in a math/science type way; thinking outside of a standard way)	1	0
Integrating CT in the Classroom	Promote problem solving skills/critical thinking in the classroom (including coding)	7	6
	Utilizing computers and technology in the classroom (Post: described using makerspace stations & coding apps; coding robotics; program with Lego WeDo)	3	6
	Not sure	2	0
Relationship of CT to Other Fields	Relates to any and all fields	4	10
	Mention of specific fields (Mathematics, Technology, Education)	2	1
	Other (related to everyday life; mentioned specific skills rather than fields)	4	0
	Not sure	2	1
Note. Fall 2019 only; *n* = 12.			

Four themes were isolated in participant descriptions of CT. The three most common themes accurately described CT as pertaining to problem solving and included problem solving, in general, solving problems *like* a computer, and solving problems *with* a computer. Six PSTs referred to problem solving themes in the preassessment, compared to 10 in the postassessment. The fourth theme was an inaccurate view of CT as the "use of computers," with two instances on both the pre- and postassessments. One PST stated they did not know what CT was on the presurvey, and three other PSTs had unique and incomplete views on the definition including, "Coding," "It is thinking in a more science and math type of way. It is incorporating those two things into one and you have to think that way," and "Thinking outside of the standard way of thinking."

When asked how CT could be integrated into the classroom, roughly half of the PSTs referred accurately to "problem solving skills/critical thinking" on both the pre- and postsurveys. Three referred to "utilizing computers and technology in the classroom" on the presurvey compared to six on the postsurvey. While using computers and technology in the classroom can be a way to incorporate CT in the classroom, using computers alone does not automatically ensure that CT is being used. PSTs who displayed this trend on the postsurvey referred to tools that we used during the semester, such as makerspace station tools, coding applications, and robotics. Two PSTs stated that they did not know how to integrate CT in the classroom on the presurvey, while none of the PSTs made this claim on the postsurvey.

To further illustrate participant views and changes over the course of the semester, four participant responses to what is CT and their associated suggestions for ways to integrate CT in the classroom are summarized as follows (see Appendix E). Participant A held the limited and erroneous view of CT as the use of computers throughout the semester; however, her view transformed to include the idea of "thought processes" needed to use a computer. Participant A also showed some growth in the types of computer usage from using computer software to complete projects at the beginning of the semester to using software for coding and makerspace projects at the end of the semester.

Participant B was consistent in her view of CT aligned with the theme as a process of solving problems. She referred to using procedures in both assessments; however, in the postassessment she claimed that students could be helped to equate using steps and procedures to "strings of code."

Participant C's view of CT transformed from the process of solving problems to the process of solving problems *with* a computer by the end of the semester. She provided a general example of asking students to use technology to solve real-world problems at the beginning of the semester. At the end of the semester, Participant C provided a specific example of CT use observed at a local STEM night, in which students could use software at the school to view and troubleshoot models of a heart or other objects such as robots.

Participant D's view of CT transformed from the process of solving problems to the process of solving problems *like* a computer by the end of the semester. She suggested adding coding activities in the classroom as a means for students to solve problems at the beginning of the semester. At the end of the semester, Participant D suggested that students could be provided problems and asked to solve them as a computer would with her example of how CT is similar to solving problems like a computer.

PSTs were asked to describe how CT relates to other disciplines and fields with examples. On the presurvey four made a statement that reflected the trend that CT "relates to any and all fields" as compared to 10 PSTs on the postsurvey. Two mentioned specific fields on the presurvey compared to one on the postsurvey, as represented by the follwoing statement: "Computational thinking relates to math and technology."

On the presurvey four PSTs described how CT related to everyday life or specific skills rather than a discipline or field, such as in the following statements:

> "Computational thinking relates to things such as working with others, solving real-world problems, fixing items, etc."
>
> "It is used in everyday lives. Once you can do computational thinking you can understand and have a deeper thinking process."

Two PSTs stated that they could not describe a relationship to other fields on the presurvey as compared to one on the postsurvey.

Assignment Reflections

Reflection of Hour of Code and Reading

In describing their experiences with the hour of code and reflections upon what they discovered from way teachers used programming, most of the PSTs described excitement and a positive disposition, including the aspects of coding and programming that they were learning, skills of perseverance and developing a growth mindset, and the importance of using these activities with children. A recurring theme found throughout the reflections was the importance of troubleshooting leading to perseverance, as represented in the following quote:

> I think the biggest take away from the angry bird activity was there were 20 different levels to complete, and I had to think a little bit about perspective and direction. … I was forced to step outside of myself in more ways than one. Grit in the classroom is a high priority for me, and coding is a great way to practice this. Overcoming a fear can be contagious. As the adult in the room I hope that learners will model an open and growth centered mindset where coding and other technology is concerned. (Fall 2019 cohort, female)

Another theme included underlying aspects of coding, such as problem-solving skills that are developed as well as ways to integrate these skills, as illustrated in the following quote:

> The good news is the building blocks for coding actually has nothing to do with computers and can be introduced and taught at even the kindergarten level. Simple logic and reasoning skills, combined with critical thinking, make up the foundation of coding and programming. Also, embarrassing mistakes and eliminating

> fear of failure is a great way to foster these skills. A more coding specific approach has many possibilities. There are numerous programs and websites available to have students learn about and delve into the world of coding. Sites like Scratch by MIT, Pyonkee, Hopscotch, Tynker, and Google CS, are just a few of the many hands-on resources available. Makerspace is also an excellent resource to find fun and engaging ways to introduce and build coding skills to elementary students. (Fall 2018 cohort, male)

The PSTs state that what they were learning should be integrated within elementary classrooms, as illustrated in the following quotation:

> I also enjoyed the Hour of Code because I think it could be a good teaching tool for introduction of Elementary Programming.... Computer programming could not be taught early enough in my opinion, and it is awesome to learn about different elementary school systems incorporating it into their curriculum. (Fall 2019 cohort, female*)*

One PST in the fall 2018 cohort felt differently: "I struggled with the hour of code. I personally did not like it, the videos for the instructions were not clear to me and I did not fully understand where I was supposed to put a lot of the codes."

Reflection of Robotics and Makerspace Inquiries

PST reflections regarding the robotics and makerspace inquiries during methods classes focused on how each tool could be used to teach subjects at the elementary level. A member of the fall 2018 cohort described how the Lego WeDo 2.0 robotics lesson that she participated in helped her learn science content about flooding, science and engineering practices, and coding skills as follows:

> I personally think that the lessons LEGO WeDo 2.0 provides are great for STEM. Any lesson selected lends itself to a variety of science topics involving technology and mathematical aspects. My particular lesson involved the exploration of flooding and how to prevent a flood, problem-solving, following directions, coding, and engineering and design. I think that this lesson would be very practical to implement in the elementary education setting, as it teaches a multitude of skills. Just based on my own exposure to this makerspace tool, I know that it challenged me to follow directions, put my coding skills to the test, and organize my thoughts and data appropriately. Therefore, this lesson would be very beneficial in the elementary classroom as well.

A member of the fall 2019 cohort described how a lesson on sun-earth-moon relationships using the Ozobot Evo helped her develop an understanding of how to make these concepts tangible for children through the experience using coding blocks to tell the robot how to perform, as follows:

> It pertains to eclipses and celestial mechanics (with Ozobot Evo) — basically, for what I did (3rd grade level), students will see how gravity pulls more when the moon is closer (causing it to travel more quickly) and pulls less when the moon is further away (causing it to slow down). When they start using a flashlight, they can see where the moon and earth's placement is for a solar and lunar eclipse to occur. This activity is beneficial to an elementary classroom as it allows students to visualize actions they may normally just read about in a textbook or watch a video of. I feel like this will allow for a more clear, better understanding of the content that is presented. Students can have fun doing it while learning a lot about the material. There are only 4 different OzoCodes used and two codes to be programmed into OzoBlockly, so it is fairly simple for third graders.

A pair of students from the fall 2019 cohort described the use of a mathematics activity using the Sphero SPRK+ robot as follows:

> We used the Sphero SPRK+ to do a perimeter activity. This was for grades 3-5, and the Sphero, along with the Sphero Edu app guided the whole thing. After a quick introduction, we drew the shapes given, looked at the sensor chart to get the measurements and solved from there. It was a very fun learning experiment. This activity was a great introduction to perimeter. It allowed students to have a way of learning that was informative while also being fun. Students are able to draw different shapes and even change the color.

A member of the fall 2019 cohort described the use of the Dash Robot to develop storytelling skills along with the science and engineering practices of communication and collaboration while developing coding skills, as follows:

> Dash Robot is an interactive tool that can help students develop new coding and robotics skills. Also, through the use of this robot, students may practice problem-solving and critical thinking skills. One way Dash could fit into curriculum is through the use of creative storytelling. For my Inquiry Assignment, I completed a lesson that was written as a creative scene or story. When using Dash, a teacher might ask students to embrace their creativity and incorporate the Dash bot into a story. Students could give Dash functions, such as, talking, moving, flashing lights, etc. Dash bot could also be used for collaboration purposes. Students could be asked to work together to solve a problem, create a story, or complete a task involving Dash. Coding Dash to make certain sounds, such as, farm animals, could help increase sensory and memorization skills. Because of this, Dash is much more than a toy. Dash can be used to teach students coding and robotics skills that will carry them throughout their life in a world of continuously-shifting technology.

Reflection of City X and 3D printing

PSTs were asked to reflect upon the process of designing a 3D product to meet the needs of a customer, constraints, and successes and challenges with the 3D design process. An illustration follows of reflections from two different teams of how they solved Allesia's needs, a citizen of City X. Allesia's profile stated, "I want to visit my cousin on the other side of this river but Mom said I'm not allowed to swim across." The first team chose to create a bridge and one team member described constraints and efforts used to troubleshoot within the following concluding reflection:

> As a team, we successfully met Allessia's need. She has a bridge that will allow her to cross over the river and stay out of the water. We all had to work very closely together in order to correctly scale our designs to fit each other's (they all required some way of being linked together). There were definitely some time constraints, as we could only work together and collaborate during class for the most part. We were successful as we met the need. There were challenges getting all of our designs to properly line up with identical measurements since they were 3 separate pieces. I struggled with the supports at first because the first support I printed did not match up with Brandon's. I fixed this by taking his finished piece and measuring how far away the holes were for my piece to fit into. This was a huge help because I could see exactly where they went. I did have to end up using sandpaper to get some of the edges off of the bottoms of the support, but once I did that the supports fit perfectly into Brandon's piece.

The second team chose to create a boat, and one team member included the following concluding reflection:

> The 3-D design process, in goal of meeting the needs of a customer, requires a good amount of trial and error and problem-solving. First, you have to reflect on the problem or situation the customer presents, and then creatively design a solution. You also have to consider major factors *and* minor factors, just as we have done with Allessia. Along with solving her problem for crossing the river, we also made sure to take protection, time, and efficiency into account. I am excited to see that it came together and although the dimensions may not be exact, the final product looks to scale. There are time constraints as with any project and design. I think that this is normal and could have been for Alessia too. I do wish we would have explored the idea of resources and available tools. This may have made the functionality of the boat a little more true to her needs and constraints.

Since each person within a team had to develop a different artifact for the solution, common challenges and constraints among every team were creating parts of the design to scale and getting the pieces to fit together to create their final product.

Lesson Plan Rationale

The fall 2019 cohort was asked to add a rationale to their lesson plans that they were able to teach in a grades 3-5 classroom, stating how the TPACK model, SAMR model, and CT in mathematics and science taxonomy (Weintrop et al., 2016) applied to the design of the lesson and activities used throughout. In the rationale for the fourth-grade lesson using Tinkercad to design animal habitats (see Appendix F, Part 1) the students were able to describe variants of PCK that they used in developing their plan. They accurately described TPK (introduction to using Tinkercad), TCK and TK (use of technology to teach the content), PK and PCK (introduction to Tinkercad, inquiry-based instruction, and use of phenomenon).

They described the use of the Redefinition level of SAMR model through the use of brainstorming the components of a habitat for a zoo animal and designing that habitat through Tinkercad and, subsequently, printing the 3D model. Finally, they described CT mathematics and science practices used within the lesson by students, including visualizing and manipulating data, designing and constructing computational models, developing and troubleshooting their computational solutions, and investigating a system and communicating information about that system.

In the rationale for the fourth-grade lesson using Lego WeDo 2.0 to design a volcano alert system (see Appendix F, Part 2) the students were able to describe variants of PCK that they used in developing their plan. They described the use of TCK (use of Legos to teach about volcanoes), TPK (introduction of ways to use Lego WeDo 2.0), and PCK (5E model [Bybee et al., 2006], phenomena, and science and engineering practices). The PSTs described the use of the Augmentation and Modification levels of the SAMR model by using the iPad to share Lego building instructions (augmentation) and building and testing a volcanic alarm robot (modification). Finally, they described CT mathematics and science practices used within the lesson by students, including modeling and simulation practices (developing a model for a volcano alert system) and computational problem-solving practices (troubleshooting code to make the robot behave appropriately).

Discussion

A limited number of preparation programs in the United States provide opportunities to develop PSTs' CT skills, and interventions of this nature are emergent with limited emphasis on developing pedagogical content knowledge. This study fills a gap in the literature by offering training that included modeling and opportunities to practice, teach, and reflect upon activities within authentic contexts (Mason & Rich, 2019; Rodriguez et al., 2019; Yadav et al., 2017).

The results of this study's interventions revealed several important findings as related to previous research and the associated research questions of this study. First the courses positively impacted PSTs' self-perceptions of TPACK (Research Question 1), as shown by a statistically significantly increase ($p< 0.001$) in scores for both cohorts. As to commonalities for the seven individual constructs of TPACK, both cohorts showed a statistically significant increase in TPK and TPACK, and neither cohort showed a statistically significant increase for TCK. The PSTs in this study had multiple opportunities to develop specific PK for teaching with different technological tools in the context of specific disciplines, beginning with an introduction to makerspace tools from fifth-grade students, completing group and individual inquiries with robotics and 3D printing, leading stations at STEM nights, and coteaching a lesson for third-, fourth-, or fifth-grade students.

These interventions were in direct response to recommendations for preparing new teachers to integrate CT within specific disciplines by redesigning educational technology courses to introduce the core ideas of CT and using methods courses to apply CT within the context of a discipline (Yadav et al., 2016, 2017). The fall 2018 cohort showed statistically significant increases for CK, PK, and PCK, while the fall 2019 cohort showed a statistically significant increase for TK.

The courses positively impacted PSTs' self-efficacy, as shown by a statistically significant increase in both cohorts' PE, as measured by the STEBI instrument (Research Question 2). Increases in PE scores correlate with a belief in the ability to teach science effectively. Elementary teachers often have a lack of knowledge and self-confidence in STEM fields. This positive change in PSTs' beliefs is meaningful (Novak & Wisdom, 2018; van Aalderen-Smeets & Walma van der Molen, 2015). Opportunities for PSTs to observe, practice, and reflect upon computing, coding, and CT interventions are a means to increase content, technological, and pedagogical knowledge and are suggested recommendations to help improve PST attitudes, self-efficacy, and beliefs (Mason & Rich, 2019).

Neither cohort showed a significant change in the average for the OE. Teachers with a high OE believe that students will be able to learn science effectively from their instruction. As described by Hechter (2010), the absence of an effect of the coursework on the OE of PSTs is not surprising, as PSTs have minimal classroom teaching experiences to provide a context for determining how well students will learn from their instruction.

In addition to the lack of knowledge and self-confidence in STEM fields, elementary teachers have a lack of confidence and misconceptions regarding CS and CT (Kaya et al., 2018; Novak & Wisdom, 2018) Participation in the courses positively impacted PST self-efficacy for and use of disciplinary CT strategies in a number of ways (Research Question 3). The fall 2019 cohort showed statistically significant increases overall on the Likert-scale items of the Teaching CT – Efficacy Assessment at the $p < 0.0001$ level.

Regarding the open-ended questions, the PST views of how to define CT and integrate CT in the classroom showed an increased awareness of the "process of solving problems," whether describing situations with or without technology. In the postassessment 10 of 12 PSTs held accurate views of CT as problem solving in general or problem solving *with* or *like* a computer, as compared to two PSTs who erroneously referred to the general use of computers as CT.

After course participation, PSTs, regardless of their views of CT, gave more specific suggestions regarding the use of tools and strategies used in the courses for solving problems, such as coding and robotics. Interventions were included as recommended by Ching et al. (2018) to incorporate disciplinary specific CT instruction, such as solving community problems and completing STEM-related projects to help PSTs see the real-world applications of CT. After participation in the courses, the majority of the students (n = 10) stated that CT relates to any and all fields and disciplines, as compared to four students at the beginning of the semester.

Rodriguez et al. (2019) and Yuan et al. (2019) claimed that PSTs often use practices and strategies that they have personally experienced; therefore, their experiences using technology and CT practices in methods courses and practicum experiences critically impacts their use as they transition to their own classrooms. PST reflections of major coursework assignments revealed an understanding and use of CT within mathematics and science instruction as well as other subjects.

Yuan et al. (2019) stated the importance of providing PSTs with opportunities for productive struggle and providing content-specific training and modeling. The reflections of the hour of code activity revealed an understanding of the need to develop a growth mindset toward mistakes made during programming. The PST reflections of robotics and makerspace inquiries focused on the engagement they had with the activities and ways the activity and tool could be used to teach specific subjects at the elementary level. The City X and 3D printing reflections revealed that the PST teams had to collaborate closely to develop and troubleshoot their plans and prototypes of their objects with a particular focus on measurement and precision.

The rationale for each lesson plan that teams developed challenged the PSTs to describe how they used different categories within TPACK to design their lesson demonstrating development in pedagogical content knowledge, which SAMR levels applied to different technology-based activities within the lesson, and specific practices used from the CT in mathematics and science taxonomy (Weintrop et al., 2016). The lesson rationales provided a clear picture of each group's understanding of these elements and illustrated a means for PSTs to showcase PK developed within the context of disciplinary CT. Teams had opportunities to discuss the rationale with the primary investigator and made modifications as needed.

Implications for Teacher Education

This study adds to the literature for preparing elementary PSTs to use and teach disciplinary CT skills. As recommended by Yadav et al. (2011), the interventions were embedded within a redesigned instructional technology course and methods courses to help PSTs develop an understanding of CT within the context of the discipline. Additionally, this study used recommendations by Mason and Rich (2019) to focus on developing PK with opportunities to practice, teach, and reflect upon activities within authentic contexts. Using these recommendations, the instructor was able to see improvements in PSTs' self-perceptions of

TPACK, Personal Science Teaching Efficacy beliefs, and teaching CT-efficacy beliefs.

The PSTs were also able to describe specific ways they could use tools for teaching elementary content and logically apply aspects of TPACK, SAMR, and the CT in Mathematics and Science Taxonomy practices to their instruction. As PSTs developed TPACK throughout the semester they made informed choices of SAMR integration within their lesson plans.

The progression of activities within these cohorts can serve as a model for other teacher educators in preparing PSTs to use disciplinary CT.

1. Developing an understanding of growth and fixed mindset at the beginning of the semester set the stage for participating in many CT activities that inherently needed attributes of curiosity and perseverance as PSTs solved problems (e.g., hour of code, inquiries, and City X).
2. Collaborating with a local school in which elementary-aged children could share how to use robotics and makerspace tools had many benefits. The PSTs were able to see that children, although not experts, can understand how to use these tools. It also helped PSTs get started with CT practices and tools, in general, without the context of a specific discipline, making it a starting point for the instructor to build upon in methods classes.
3. Explicitly introducing the TPACK and SAMR models helped the PSTs develop vocabulary and served as frameworks that they could use as we engaged in activities and discourse throughout the semester to process what they were learning as they developed professional dispositions.
4. The robotics and makerspace inquiries, as well as the 3D printing and City X project, worked as the next steps toward making explicit connections with elementary mathematics and science curriculum.
5. The PSTs were able to lead multiple stations at local STEM nights and train other PSTs from different sites with how to use these tools. In most cases these opportunities allowed children to practice CT as an isolated skill and allowed the PSTs to practice teaching.
6. The PSTs cotaught a disciplinary CT-based robotics/makerspace lesson in schools. The instructor was able to coteach with each team and provide feedback on the spot, and in most cases the teams taught the lessons two to three times.

Finding additional resources in the community, such as the ORNL Manufacturing Demonstration Facility and Women in Computing roundtable, helped PSTs develop local connections and describe how these skills are used in future careers (fall 2019 cohort). Opportunities to attend conferences along with in-service teachers such as the STEM BOSS conference (fall 2018 cohort) and present at conferences (fall 2019 cohort) helped PSTs see how teaching is a lifelong process of professional growth and sets the stage for seeking PD opportunities in the future.

Conclusions

These methods courses intentionally advanced research on the use of CT within elementary mathematics and science classrooms by including the use of innovative cyber technologies (e.g., robotics, programming, and 3D printing) and by using interdisciplinary approaches in the classroom. Grover (2018) argued, "Like any skill, CT is best taught and learned in context, and embedded into class subjects." Methods courses and instructional technology courses can each play a role in providing opportunities for PSTs to practice using, teaching, and reflecting upon disciplinary CT activities and practices. As PSTs increase their TPACK by developing content and pedagogical skills with the use of technology within specific contexts, they are better suited to identify the appropriate SAMR level to meet their instructional needs.

Next steps include collaborating with CS educators and integrating CT within other methods courses within our teacher education program (Yadav et al., 2011). This step would allow PSTs to have multiple exposure points for the use of CT within context and increase their chances of transfer to the classroom. Ching et al. (2018) suggested that as students collaborate instructors should look for teachable moments as PSTs make their CT knowledge visible. This approach presents an opportunity for methods instructors to illuminate CT-related discourse and, in turn, ask PSTs to observe academic language use and discourse by elementary children. Methods instructors need to help PSTs make explicit connections to TPACK, SAMR, and CT practices throughout each course through written and oral reflections.

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Appendix A
Sample Student Artifacts

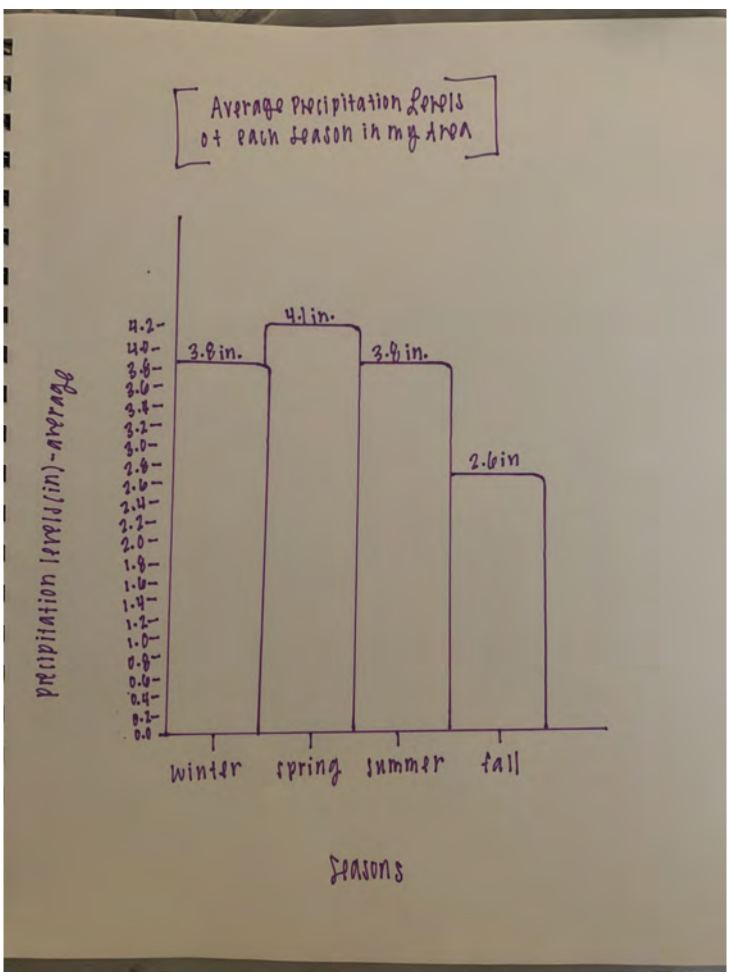
Makerspace Inquiry Project - Documentation

Key Objectives:

In this project, you will:

- Explore various ways that precipitation can change over seasons and how water can cause damage if it is not controlled.
- Create and program a floodgate to control the water level of a river.
- Present and document multiple solutions designed to prevent water from changing the shape of the land.

1. **Explore Phase:** Max and Mia are considering different kinds of precipitation in their area. They want to know how to keep precipitation from impacting the land in their area.
   Explore Max's and Mia's Questions:
   1. Can you describe precipitation levels of each season in your area using a bar graph?
      Student Response:



2. How does precipitation influence river water levels?
   Student Response: The more precipitation or rainfall, then the higher the water level in rivers.

3. What are some different ways you can prevent a flood?
   Student Response: The use of effective drainage systems, retaining walls, and vegetation are some different ways in which a flood can be prevented.

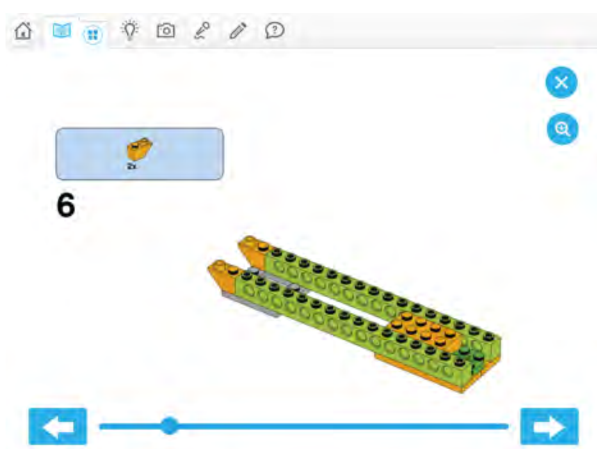
4. Can you imagine a device that can prevent a flood from happening?
   Student Response: A device that could prevent a flood from happening could be a floodgate.

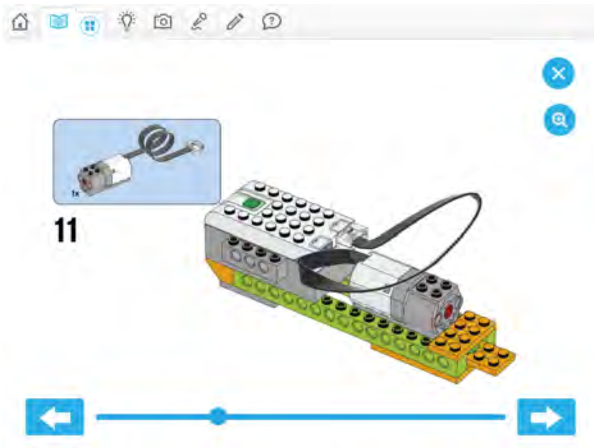
2. Create Phase

- ❑ Use the bricks:

Build a floodgate that can control the level of water in a river.

Create Phase Student Documentation: The chart below includes important screenshots of programming for the iPad, as well as my personal creation with the Lego's. The documentation does not show every individual step of creation, but rather the essential steps in which visible progress is noted.

Screenshot	Personal Creation
	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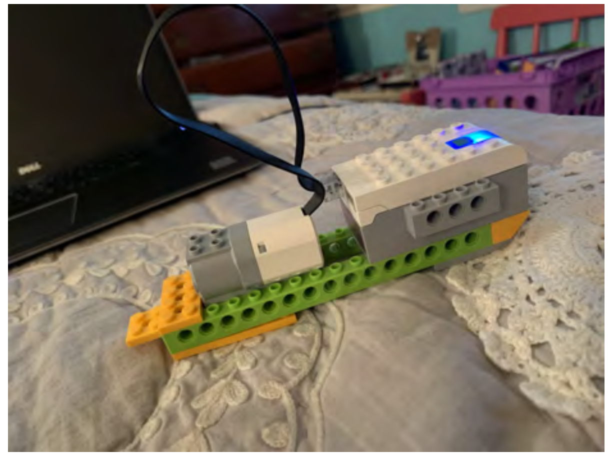
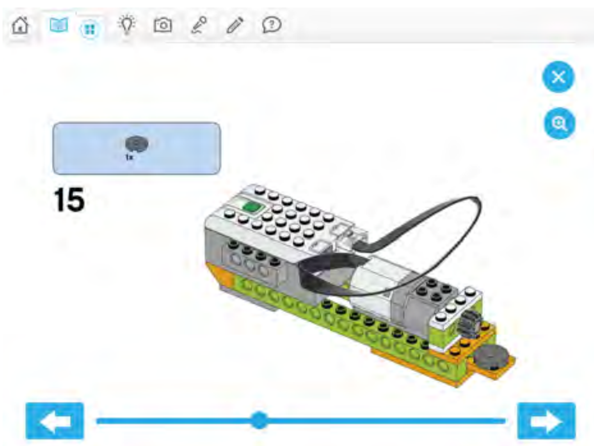
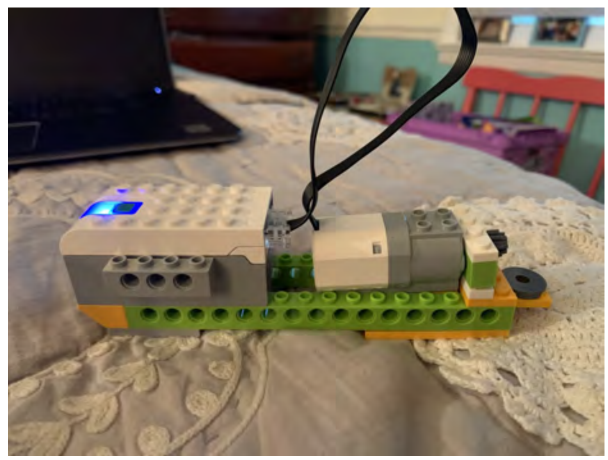
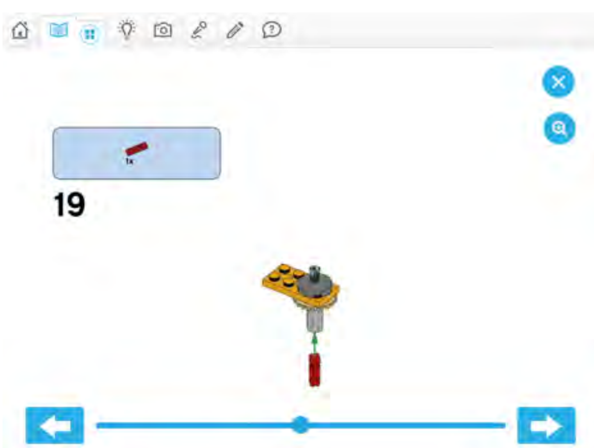
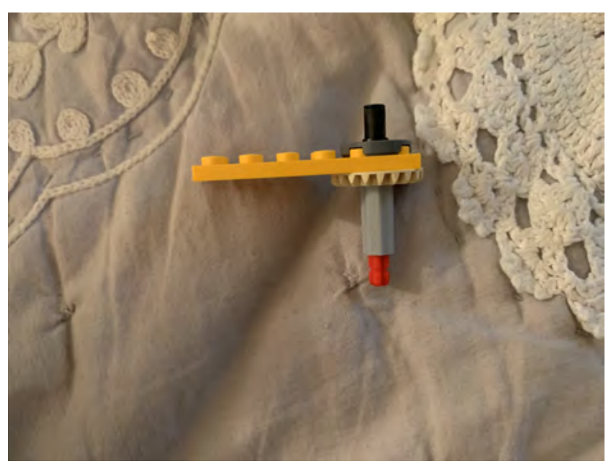
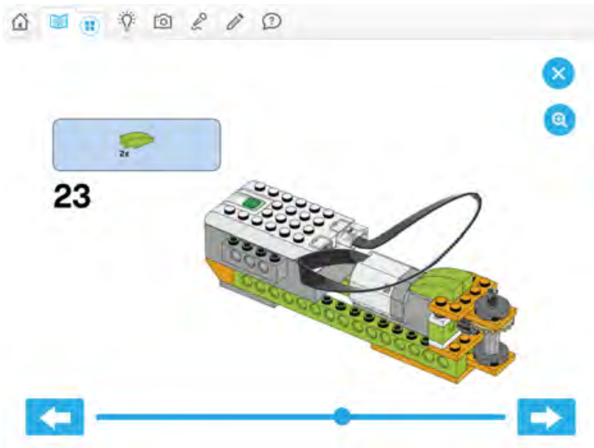



15




19

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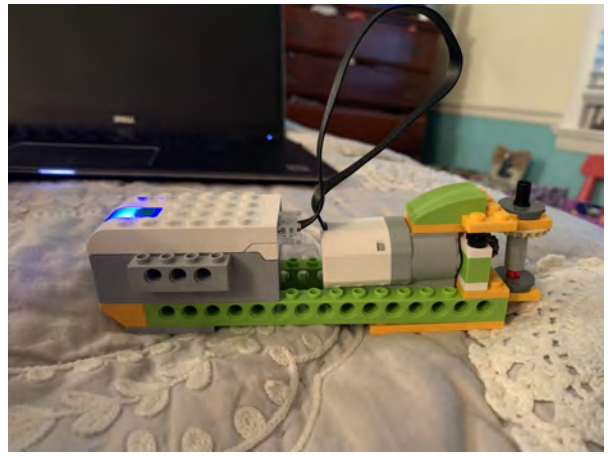

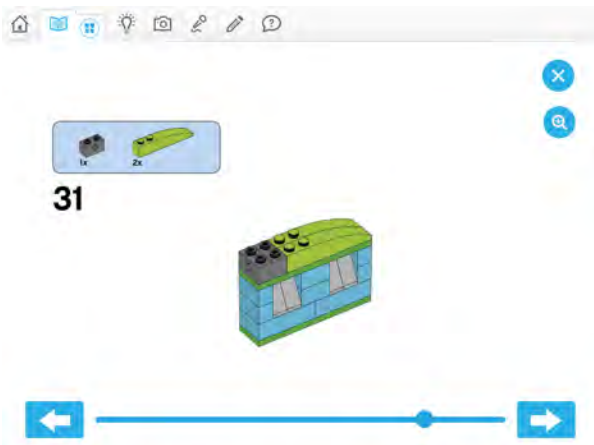
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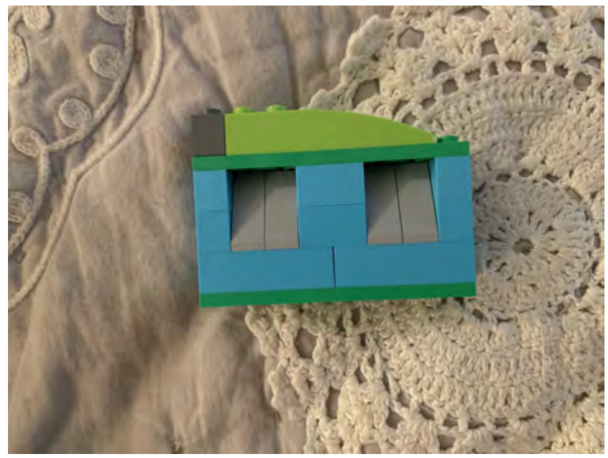
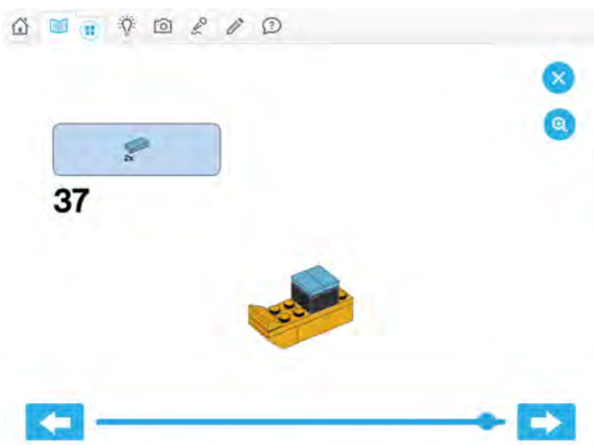
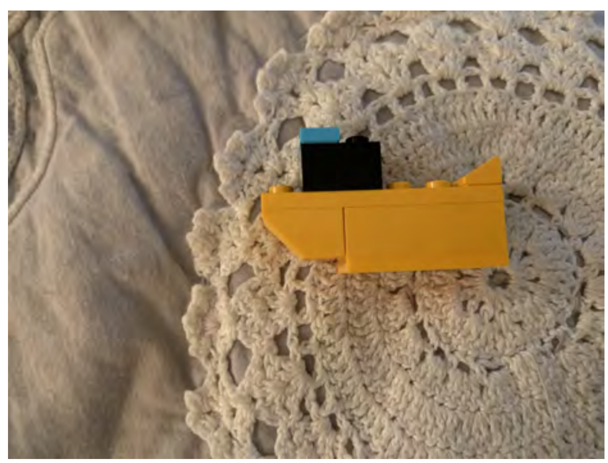
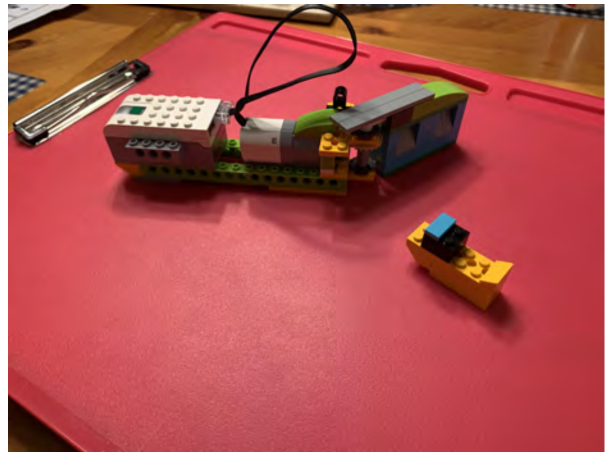



37





- ❑ Connect your Smarthub
  Turn on the Smarthub and connect it your device.

- ❑ Program your Model
  Program your floodgate to open and close at the appropriate time according to your bar graph.

Program Model Student Documentation:
My task was to create a floodgate that would open and close at the appropriate time according to my bar graph. I could not include the entire code in one screenshot, so I broke the code down based upon each season. I programmed the floodgate to stay open the longest amount of time in the spring because that's when my area receives the most precipitation. I programmed the floodgate to stay open the shortest amount of time in the fall because that's when my area receives the least precipitation. Lastly I programmed the floodgate to stay open for the same amount of time in the summer and winter because that's when my area receives about the same amount of precipitation. Note that it is rather difficult to spot the differences in the amount of time the floodgate is actually open due to the small difference in precipitation each season receives. The video features the entire code for each season opening and closing in one segment.

Season	Individual Code for Each Season
Winter (4 Seconds)	
Spring (5 Seconds)	
Summer (4 Seconds)	
Fall (2 Seconds)	

I haven't completed this lesson before so it was really great to see how it was organized and the process involved. I love the functionality of creating a movable gate controlled remotely by programming- can help students see the functionality in the real-world.

❑ Design a Solution (Extension)

Consider one of the following:

1. Add a Tilt Sensor handle to operate the gate.
2. Add a Motion Sensor to detect water rising.
3. Add a Sound Sensor Input to activate an emergency protocol.

<u>Student Response:</u> At this point, I went over my 90 minutes in order to complete the extension portion of the lesson.

3. Share Phase

- ❏ Share your findings: Present in your own words how a floodgate can prevent water from changing the shape of the land:
  Student Response: The goal of a floodgate is to control water flow in flood barriers, rivers, streams, and other bodies of water. Water can cause the land to change shape by carrying soil and rock to new places and depositing them in other areas. If a floodgate is present, then there will be a decrease in water overflow that alters the shape of the land.

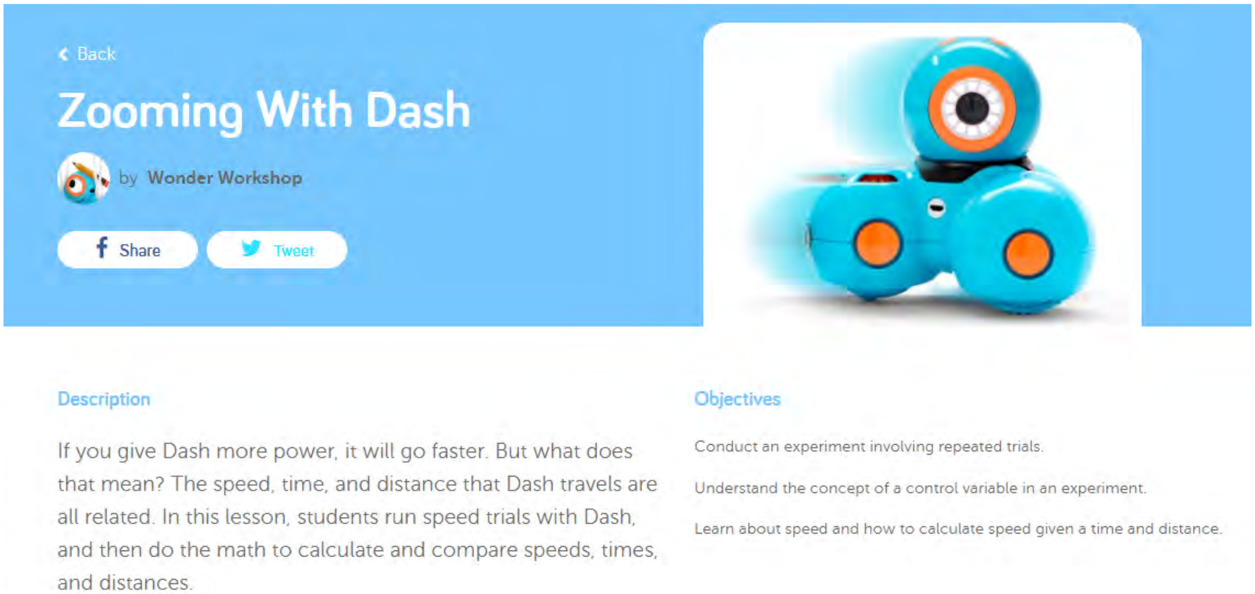
QR CODE:

Reflection

I completed the Makerspace Inquiry Project using the LEGO Education WeDo 2.0 kit and app. The LEGO Education WeDo 2.0 kit and app could be used in a variety of ways in the elementary classroom. When implementing this tool, students are forced to use a variety of skills and learned tasks such as following directions in order to build the creation, organizing and documenting their steps in a logical way, problem-solving various prototypes and extended features of their model, and basic coding and computational skills. Science, math, and technology are all subjects that would lend themselves to being useful for this tool. However, this makerspace tool could be implemented in almost any subject, as long as the framework of the lesson is adapted to what is being studied. The teacher must prepare the information necessary for the given task, allow students time to create, and have students share what it is that they created and why. I personally think that the lessons LEGO WeDo 2.0 provides are great for STEM. Any lesson selected lends itself to a variety of science topics involving technology and mathematical aspects. My particular lesson involved the exploration of flooding and how to prevent a flood, problem-solving, following directions, coding, and engineering and design. I think that this lesson would be very practical to implement in the elementary education setting as it teaches a multitude of skills. Just based on my own exposure to this makerspace tool, I know that it challenged me to follow directions, put my coding skills to the test, and organize my thoughts and data appropriately. Therefore, this lesson would be very beneficial in the elementary classroom as well.

Inquiry Part 2

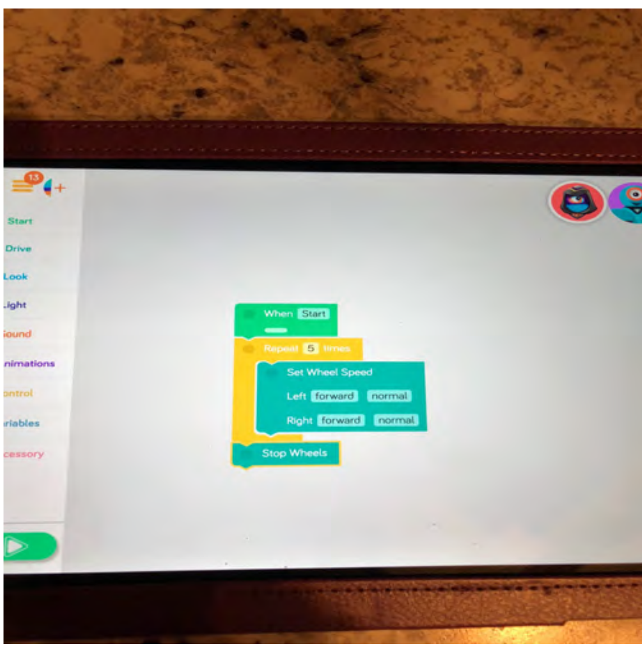
Dash & Dot

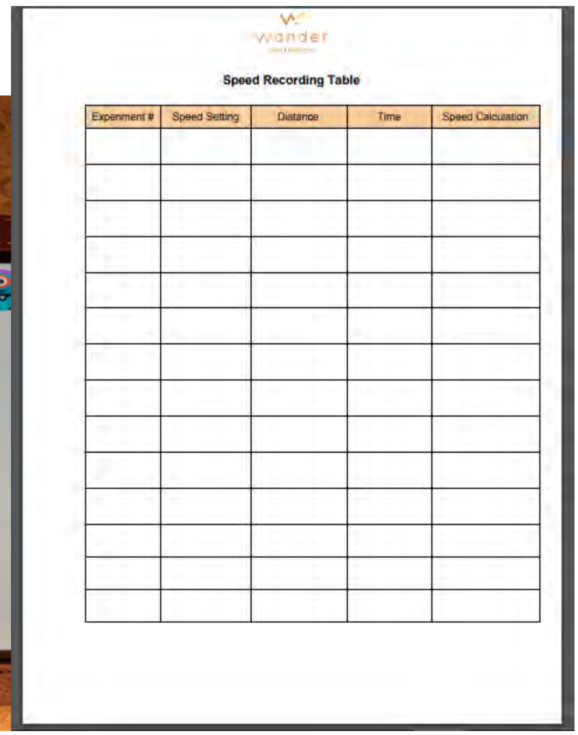


https://education.makewonder.com/curriculum/zooming-with-dash

In this activity, students get to explore science and math with Dash. Students are to write a hypothesis about how speed will affect the distance that Dash will go and experiment to prove whether their hypotheses are true or false. Students will be learning about how speed equals distance over time and how they can solve these math equations. During this activity, a worksheet will be available for students to fill out to record their work about speed setting, time, and the distance Dash traveled. For this activity, I had to construct a racetrack (start and finish line), form a hypothesis, and experiment by coding the Dash, using a stopwatch, and measuring distance. I had to code using Blockly to make Dash move forward in a straight line. However, there were different speed settings that could be adjusted that helped me prove my hypothesis was true: The higher the speed setting, the farther the distance.

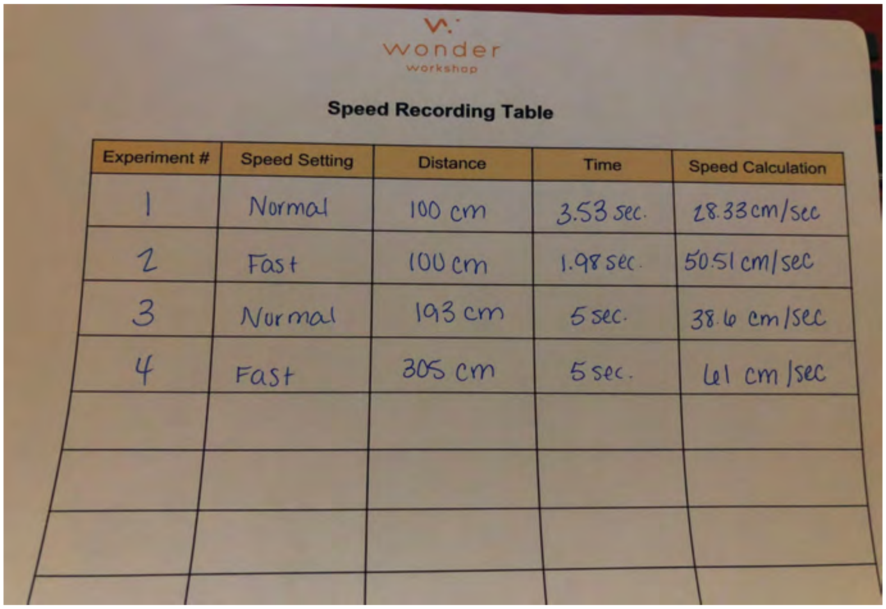
Video Demonstration:
https://drive.google.com/open?id=1YeIi7zKjgbK11QE1eWPUtz3oC0_3heQ1





Speed Recording Table

Experiment #	Speed Setting	Distance	Time	Speed Calculation


wonder
workshop

Speed Recording Table

Experiment #	Speed Setting	Distance	Time	Speed Calculation
1	Normal	100 cm	3.53 sec.	28.33 cm/sec
2	Fast	100 cm	1.98 sec.	50.51 cm/sec
3	Normal	193 cm	5 sec.	38.6 cm/sec
4	Fast	305 cm	5 sec.	61 cm/sec

How Dash can be Used in the Elementary Classroom:
Dash can be used in the elementary classroom by students learning science, math, and coding. Students have to code Dash to set him at a certain speed or for a time frame. Students use coding to measure and distance, time, and speed. This is great for elementary classrooms that are covering these topics. and they could incorporate math and science together for children who dislike one subject over the other. The students are able to create experiment and solve for solutions. Most children like playing with Dash, so I believe they would enjoy this lesson as much as I did.

Appendix B
City X Activity
Part 1 - Team Members:

<table>
<tr>
<td>Include a Screenshot of the City X Citizen(s) that you selected here.

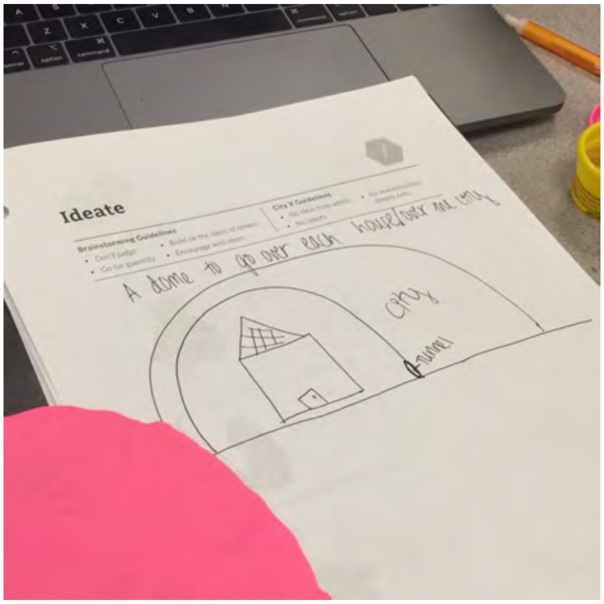


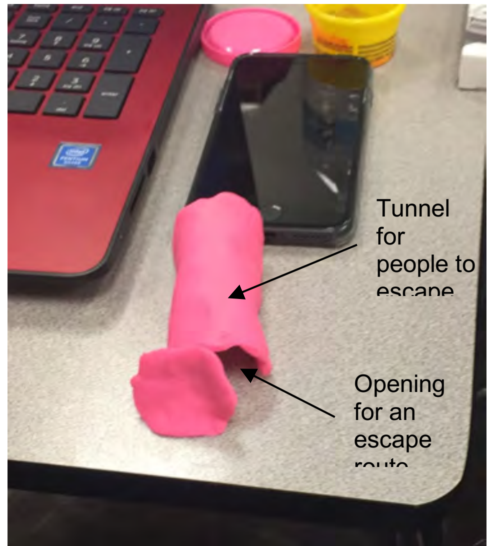
</td>
<td>Describe what you chose to design for your citizen(s) and why.

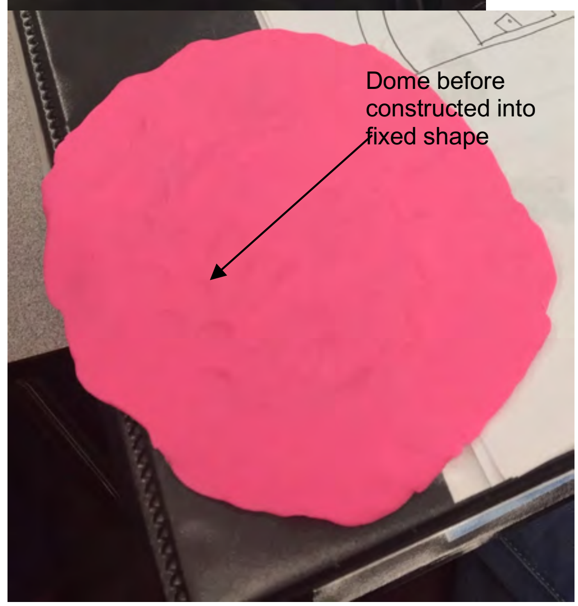
We chose to build a house for Suzana because she requested a real home in City X. We thought building a house would be a really fun project to build and create.

The dome was invented to cover the houses in order to protect them from the meteors. This was a hazard that the people of City X, including Miya, feared since the planet is in an asteroid belt. We also added on a tunnel to give them an easy way to escape the dome.</td>
</tr>
<tr>
<td>Include a picture of your sketch of your prototype(s). Include a description of the dimensions that you selected for the different parts of your prototype and why you selected these dimensions.</td>
<td>Include a picture of your prototype(s) made out of playdough (if you have them). Include image annotations for what each part is and what is unique about your design.</td>
</tr>
</table>

We selected the dimensions of 12cmx12cmx12cm for our dome. We made sure it was going to be large enough to cover the homes on Planet X. The tunnel's dimensions are 5.5cmx2.3cmx5.0cm. We made this tunnel small for the safety of the people on the planet.







The dimensions of the basement of our house is 8cmx8cmx3cm. We thought this would be a nice size basement for storage, as well as safety precautions, like asteroids.

The dimensions of our supports, the chicken feet, are 2.9cmx2.9cmx2cm

The dimensions of the cone, the top of our house, is W 8.0 cm x L 8.0 cm x H 8.1 cm

<table>
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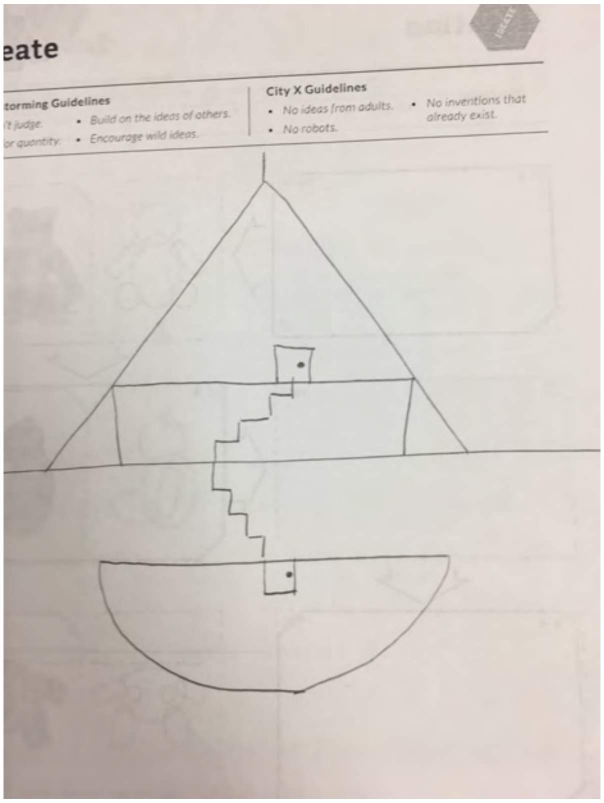
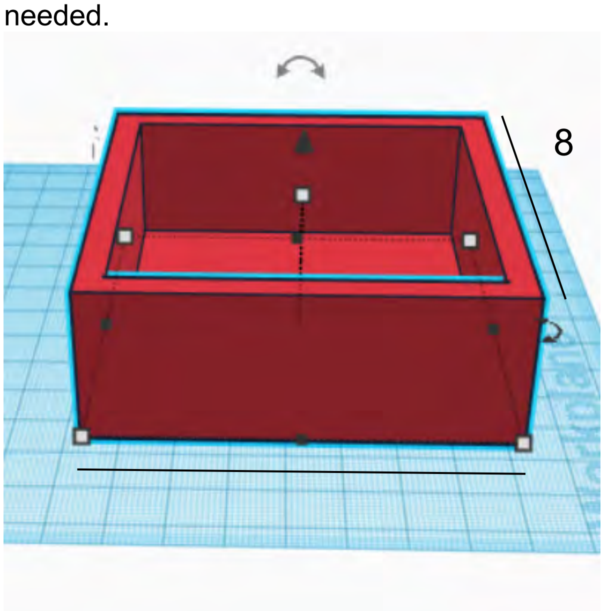
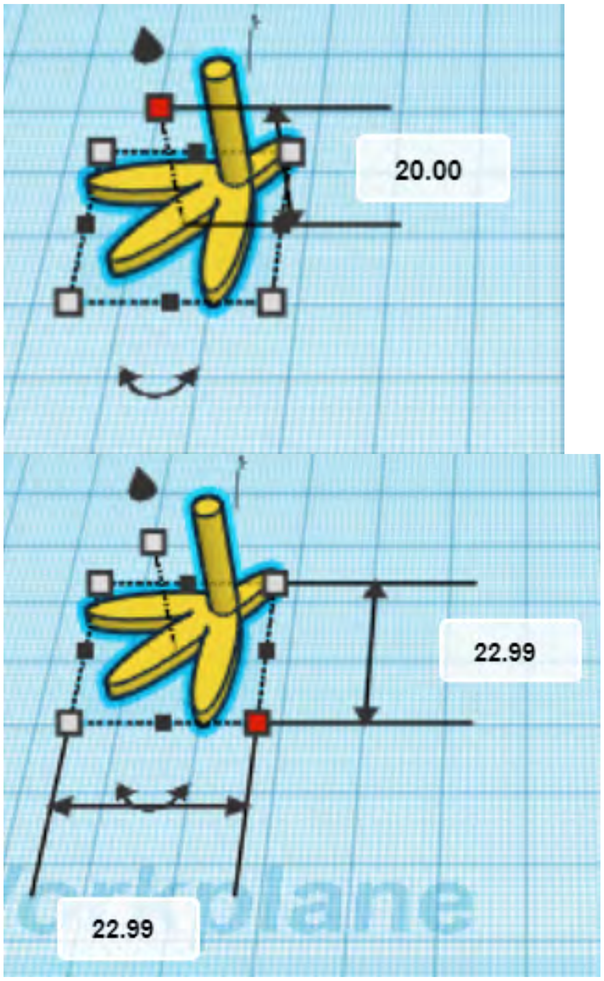
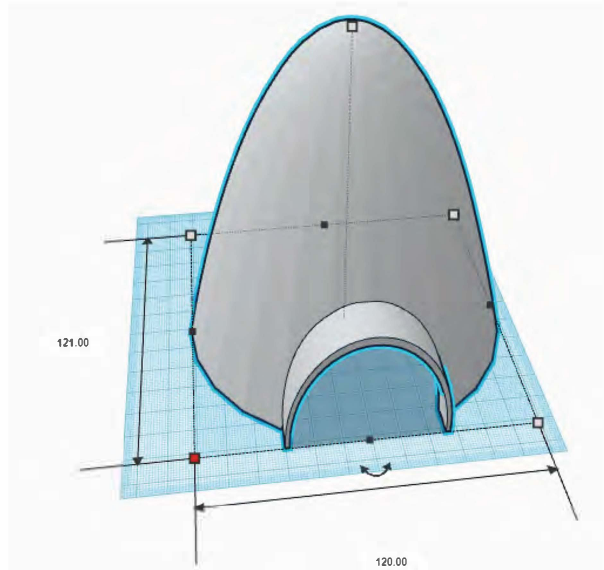
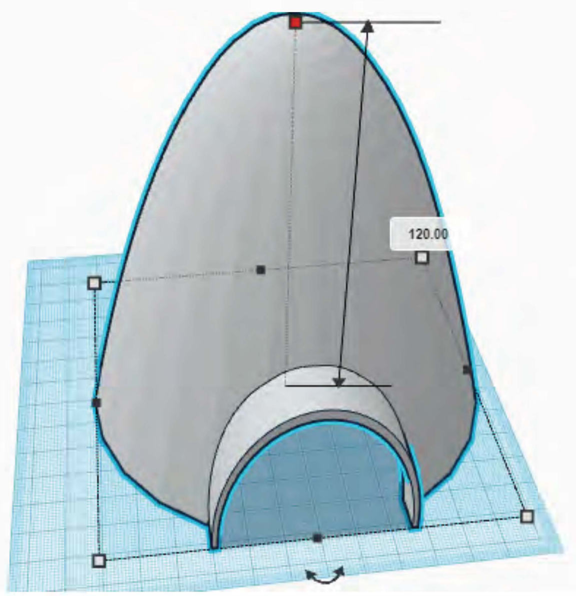


</td>
<td></td>
</tr>
<tr>
<td>
Include a screenshot of your designs made with Tinkercad as well as a link to your design for each member of the group. The link can be generated using this symbol. Include the dimensions that you used to create your prototype. Use image annotations as needed.


</td>
<td>Include photos of your final 3-D printed product.</td>
</tr>
</table>

 https://www.tinkercad.com/things/fEau14yLxuJ-chicken-feet-supports/edit	 


121.00
120.00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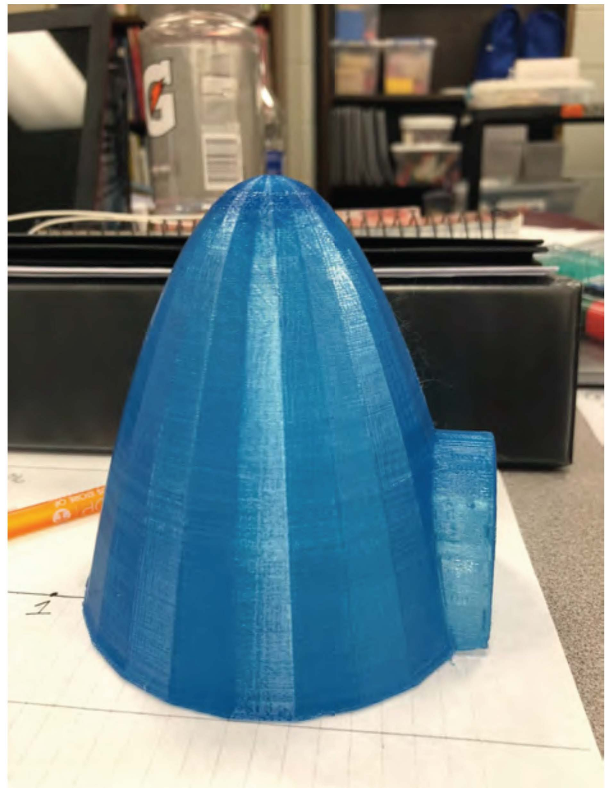
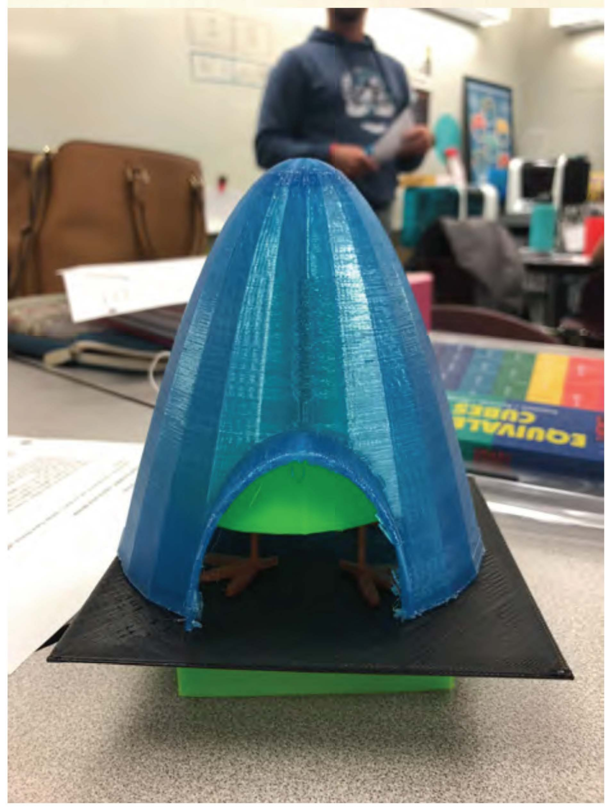
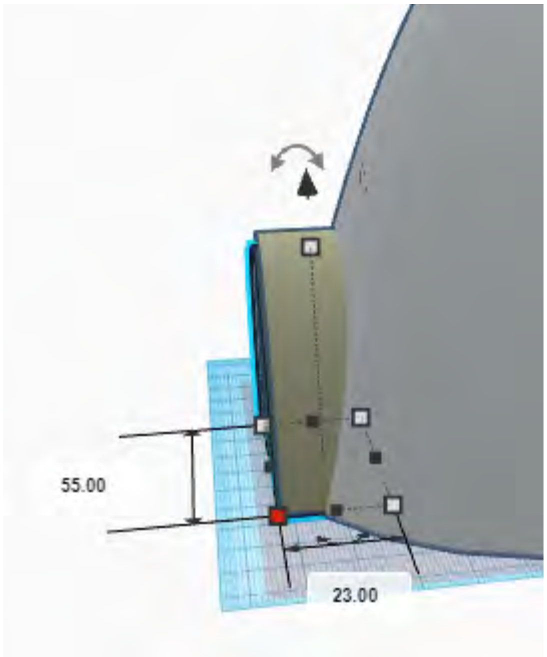




  https://www.tinkercad.com/things/2MJngRPNBWu-fantastic-jaiks-krunk/edit?sharecode=yqhrGShv_wpurbyctOsv1HGlqAo6_qsaCXvr8C-2UNA=	

Reflection
As a team reflect on the process of designing a 3D product to meet the need of a customer. What constraints do you feel that you were working with? Describe your successes and challenges with the 3D design process.

We combined the demands of Suzana and Miya by creating a new home with protection. It was hard to make a house without knowing the size of Suzana's family as well as any other demands. With the dome, it was hard to figure out if the material it's made out of could withstand the damage by a meteor.

The major issue we ran into was hollowing out the house. Being precise enough to have a hollow house while still keeping a floor to the house was a complicated process. We also had challenges with making a window for our house for people to look through. We started by trying to make the window in a star shape. After many unsuccessful attempts, we gave up and made the window circular.

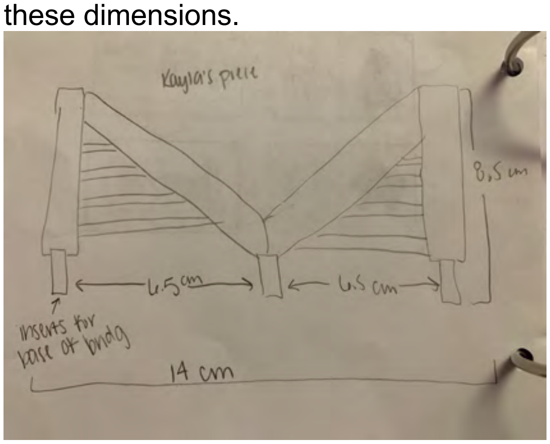
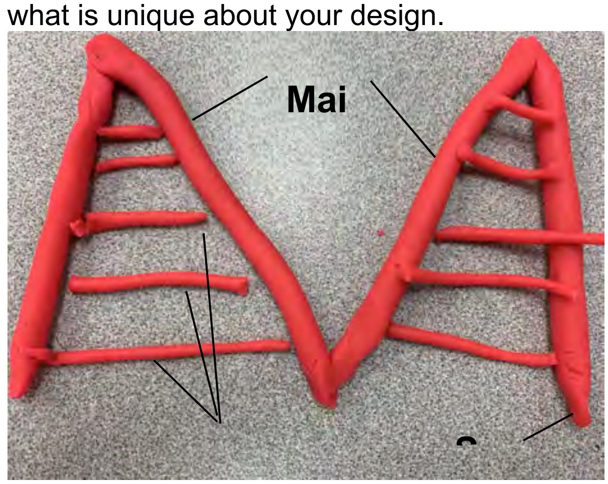
With the demands of Miya, we created a dome that can be used as a security unit to protect the citizens from possible meteors. The major issues when constructing this dome was making it hollow, forming the tunnel into the dome so the citizen could have an escape route, and our first 3D print messed up. However, we had a great success! We were able to overcome our complications and our second 3D print turned out great!

How to Annotate images in Google Docs

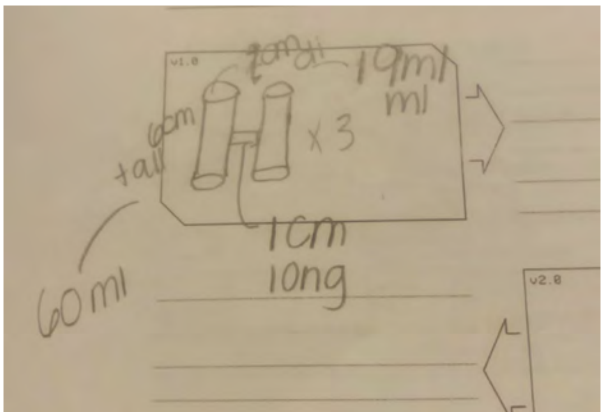
- Insert “Drawing”
- Upload screenshot or photo to drawing tool and then add arrows and text boxes as desired.

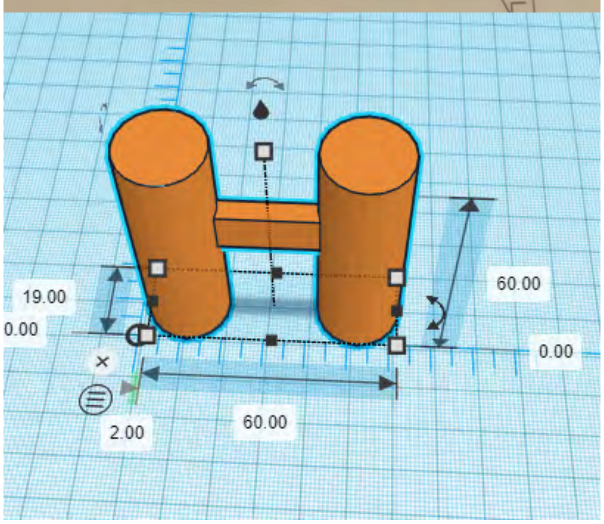
Free Online image editor:
https://screenshot.net/online-image-editor.html
11 Best online Photo Editors: https://www.format.com/magazine/resources/photography/best-online-photo-editors-free

Part 2 - Team Members:

Include a Screenshot of the City X Citizen(s) that you selected here.  	Describe what you chose to design for your citizen(s) and why. ● We all chose to design a bridge for Allessia. She needs to cross the river, but isn't allowed to cross, so we immediately decided to keep her out of the water completely and design a bridge for her. This way she will be able to cross the river and see her family while still listening to her mom and not swimming across.
Include a picture of your sketch of your prototype(s). Include a description of the dimensions that you selected for the different parts of your prototype and why you selected these dimensions.  Kayla's Prototype: Bridge Archway	Include a picture of your prototype(s) made out of playdough (*if you have them*). Include image annotations for what each part is and what is unique about your design.  The bridge supports (horizontal slats across

I chose these dimensions because it was proportional to the size we chose of the bridge as a whole. We took the total height and width of the bridge and basically split it for the top and bottom half (height). There will be two separate archways to go on each side of the bridge.

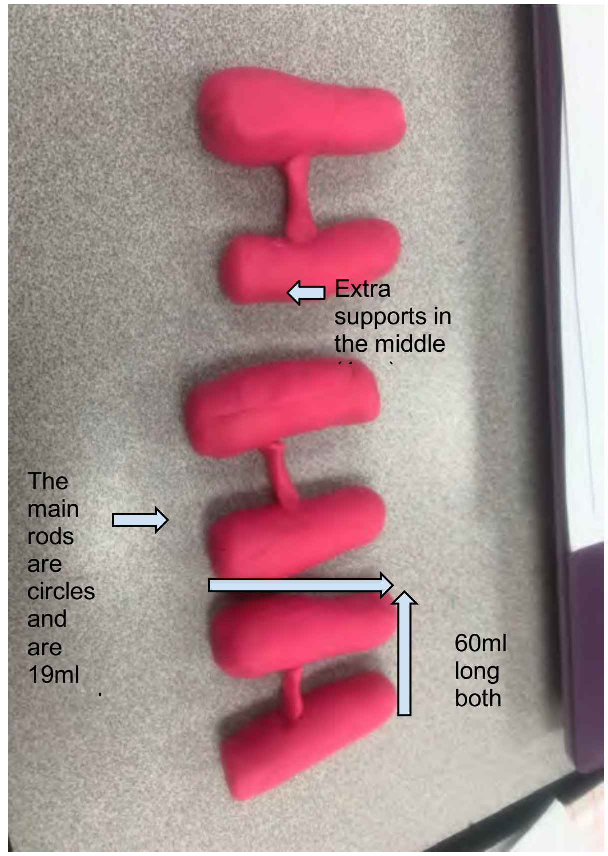




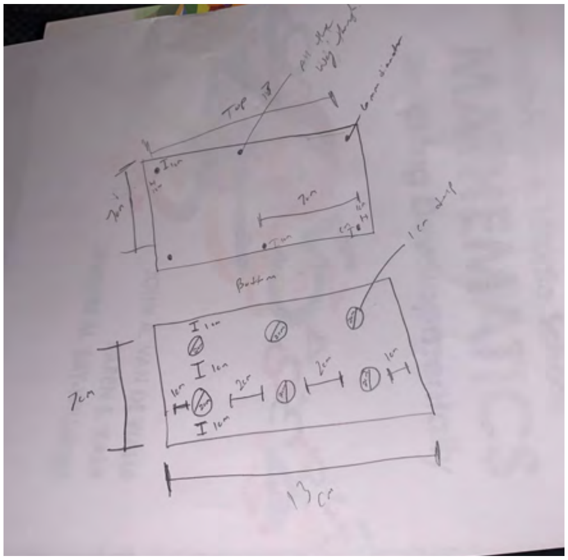
Molly's Prototype: Bottom of bridge supports
I used my measurement based off of Brandon's bridge piece. The circles at the top of the bridge and the bottom had to be 19 mm. The support in the middle (shown in the picture above) had to be 1 cm long. The supports were 6cm tall. The most important measurement was that the total length of the bridge had to be 60 mm. This was so important because I wanted mine to snap into Brandon's just enough that it would stand up. I have four total support pieces for the bottom of the bridge.

the archway) for the archways are what is unique with my design. Traditionally, the additional supports run vertically, but we saw it best fit for the design to run horizontally.

BE CAREFUL TO ANNOTATE IN MM INSTEAD OF ML.



The bottom of the bridge supports were designed originally with just the two thick sections for each support. I then added a smaller support horizontally between the thick pieces.



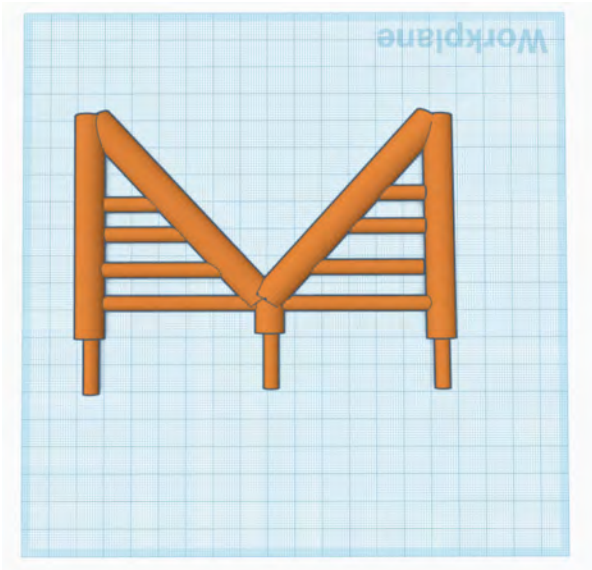
Our middle level of the bridge consisted of a being a thick block which is 7cm by 13cm. On the bottom of the bridge it has 6 half cut holes that are made for the cylinder supports that were made by Molly. The half vertical cut holes have a 2cm diameter. On the top of the bridge there are 6 holes that are cut all the way through, these holes allow Kayla's arches to snap in place and stay. These holes are .6 mm in diameter to be a little bigger than kayla's diameter of her arches.

The middle part of the bridge is made to be thick so that it can support the weight of whatever travels over it and also the arches. It has 6 holes on the bottom for the cylinder shaped supports to go into and 6 holes on top for the bottom of the arches to snap into to hold the arches secure.

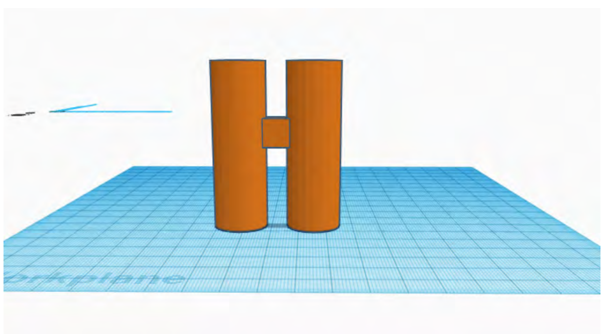
Include a screenshot of your designs made with Tinkercad as well as a link to your design for each member of the group. The link can be generated using this symbol. Include the dimensions that you used to create your prototype. Use image annotations as needed.

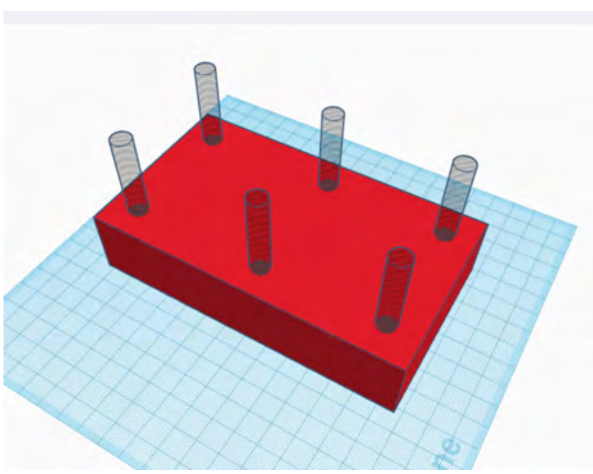
Kayla:
https://www.tinkercad.com/things/cDzBX3symsy-bridge-arch/edit?sharecode=QTyjTwfDIa-IdU6ObXYahNjulct2Z-fCiK7v_yQ3MDc=

Include photos of your final 3-D printed product.
First print (Kayla): 5 inches wide by 4 inches tall (127 mm x 101.6)



Molly:
https://www.tinkercad.com/things/dh7tupuFol1-bridge/edit

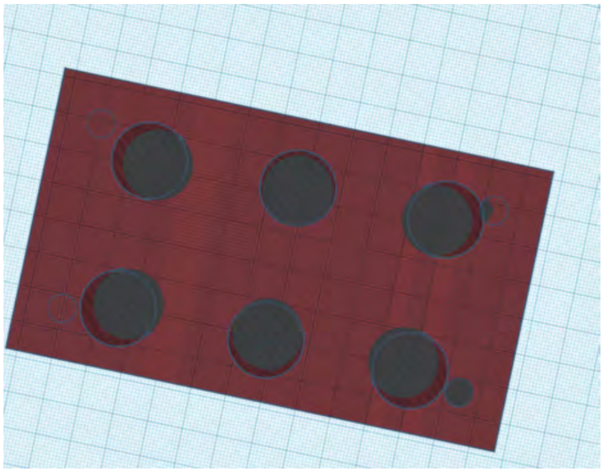




Brandon (I struggled to get the tape off)

Molly- Supports

Final

 https://www.tinkercad.com/things/3usvC9aA6Eh-city-x-project/edit	 

Reflection
As a team reflect on the process of designing a 3D product to meet the need of a customer. What constraints do you feel that you were working with? Describe your successes and challenges with the 3D design process.

As a team, we successfully met the Allessia's need. She has a bridge that will allow her to cross over the river and stay out of the water. We all had to work very closely together in order to correctly scale our designs to fit each other's (they all required some way of being linked together). There were definitely some time constraints as we could only work together and collaborate during class for the most part. We were successful as we met the need. There were challenges getting all of our designs to properly line up with identical measurements since they were 3 separate pieces. I, Molly, struggled with the supports at first because the first support I printed did not match up with Brandon's. I fixed this by talking his finished piece and measuring how far away the holes were for my piece to fit into. This was a huge help because i could see exactly where they went. I did have to end up using sandpaper to get some of the edges off of the bottoms of the support, but once I did that the supports fit perfectly into Brandon's piece.

Originally, the holes from my bridge arch didn't line up with the holes in Brandon's bridge base. To correct, I remeasured and had to shrink it by a cm.

How to Annotate images in Google Docs

- Insert "Drawing"
- Upload screenshot or photo to drawing tool and then add arrows and text boxes as desired.

Free Online image editor:
https://screenshot.net/online-image-editor.html
11 Best online Photo Editors: https://www.format.com/magazine/resources/photography/best-online-photo-editors-free

Appendix C
Example Lesson Plans and Reflections
Part 1

Name:	Date: 12/9/19
Lesson Topic: Beach Cleanup DASH	Grade Level: 5th grade

Curriculum Standards
TN Science Content Standards: 5. ETS1: Research, test, re-test, and communicate a design to solve a problem. 5. PS1. 2: Analyze and interpret data to show that the amount of matter is conserved even when it changes form, including transitions where matter seems to vanish. 5. PS2. 2: Make observations and measurements of an object's motion to provide evidence that a pattern can be used to predict future motion. **Component Idea:** Developing Possible Solutions **Tennessee Digital Readiness Standards** 5.CCP.4 Create an algorithm which includes structures to solve a problem using visual block-based and/or text-based programming language both collaboratively and individually. AIT.2 Develop a plan to use technology to find a solution and create projects. CC.3 Contribute, individually or as part of a team, to work to identify and solve authentic problems or produce original works using a variety of digital tools and devices. CC.1 Interact with peers, experts, and others using a variety of digital tools and devices.
Science and Engineering Practices: 1. Analyzing and Interpreting Data: Students should organize data, observations and measurements) in a manner which facilitates further analysis and comparisons. 2. Using mathematics and computational thinking 3. obtaining, evaluation, and communicating information
Crosscutting Concepts: 1. Cause and effect is being used as the students are creating the prototype and the final program for their Dash. They will need to test a command and analyze the outcome in order to make decisions about efficiency. 2. Systems and system model 3. scale, proportion and quantity
Central Focus
Central Focus Statement: Designing and testing using a trash collecting dash bot in order to solve environmental problems that are focused on the idea that we need to recycle, reuse, and improve the way we use our resources.
Real-World Phenomena: Sea turtles and other oceanic animals are dying from eating straws and trash that is left on the beaches.
3-Dimensional Lesson Objectives (or Multi-dimensional)
1. The student will be able to design a solution for the given problem of making the environment more safe and clean. 2. The student will be able to communicate possible solutions by analyzing the results of their designed trash collecting dash bot. 3. The student will be able to organize their data in a manner which facilitates further analysis and comparisons in regards to their prototype.

Language Demands		
	Word(s) or Descriptions	Supports
Language Function	Analyze	CER template Data Sheet Teacher instruction Blockly
Subject-Specific Vocabulary (Tier 3)	Dash, Blockly, coding, prototype, program, recycle, reduce, reuse criteria, grid, constraints, proximity	Slideshow- (programming instructions) teacher instruction
General Academic Vocabulary (Tier 2)	design, function, solution, direction, explain, evaluate, explore, data, seconds	Data sheet Slideshow CER template examples
Syntax	1. Students will be able to refer to the Dash/Blockly slideshow to help them see the steps required to make the dash function for the project given. 2. Students will be able to understand, and use coding and coding language. 3. Documenting efficiency of trash pickup path (quantity/time)	Slideshow (Dash instructions) Slideshow (Makerspace) Teacher model on Ipad and computer.
Discourse	1. Students will be engaging in discourse with team members and teachers to make plans for programming 2. Documenting the results in their CER statement 3. Students will be able to use the Makerspace slideshow to understand the instructions and goal of the activity and verbally talk about what needs to be done with their peers.	Teacher model Peer model Data sheet provided

Assessment/Evaluation			
Formative			
Connected Objective(s)	Name & Description	Evidence Collected of Student Understanding	Location in the Lesson
• The student will be able to organize their data in a manner which facilitates further analysis	**Thumbs Up, Thumbs Down:** After the class has reviewed the instructions for the data table, the teacher will make a quick note of	Based on students showing their thumbs at various positions, the teacher will be able to quickly note if students feel comfortable in their	Instructional Procedures

and comparisons in regards to their prototype.	student understanding/ comfort level in regards to how to complete and fill out the data table by students thumb positions. Thumbs up = Good understanding in regards to how to complete the data table. Thumbs down = Lacking good understanding in regards to how to complete the data table. Horizontal thumbs = Partial understanding in regards to how to complete the data table.	understanding in regards to how to complete the data table.	
• The student will be able to design a solution for the given problem of making the environment more safe and clean.	**Fist to Five:** Fist to Five asks students to indicate the extent of their understanding of a concept, or directions for an activity by holding up a closed fist (no understanding), one finger (very little understanding), and a range up to five fingers (I understand and I can explain it to someone else.	Based on students showing their fingers at various positions, the teacher will be able to quickly note if students understand their given task: "There is a beach that is in desperate need of trash pick-up. We need to help make this beach clean again by using art and technology to tackle the challenge. Your task is to design and build trash collecting robots."	Set
• The student will be able to design a solution for the given problem of making the environment more safe and clean.	**Data Table:** The students will fill-out a data table throughout the completion of creating prototype #1 and prototype #2. The data table will have students explain their design (What materials they used and how they	While students are completing the design and documentation process for each prototype, the teacher will circulate amongst each group. The teacher will make mental notes in regards to how students are	Instructional Procedures

- The student will be able to communicate possible solutions by analyzing the results of their designed trash collecting dash bot. - The student will be able to organize their data in a manner which facilitates further analysis and comparisons in regards to their prototype.	went about building each prototype). The data table will also have students document the success of each prototype (Dash bot collected a substantial amount of trash = 3. Average amount of trash = 2. Only a few pieces of tash =1)	present the results of their designed trash collecting dash bot and documenting the description of their designs.	

Summative

Connected Objective(s)	Name & Description	Evidence Collected of Student Understanding	Evaluation Criteria
- The student will be able to communicate possible solutions as well as present the results of their designed trash collecting dash bot. - The student will be able to organize their data in a manner which facilitates further analysis and comparisons in regards to their prototype.	**CER Template:** CER (Claim, Evidence, Reasoning) is a format for writing about science. It allows you to think about your data in an organized, thorough manner.	- The CER template will serve as a measurement in which student understanding can be evaluated. - By completing the CER template, students will have the opportunity to demonstrate the results of their design, and their understanding as to why prototype #1 or prototype #2 was more successful.	- Students will be graded on the CER scoring rubric. - The claim, evidence, and reasoning can be scored on a scale from 1 to 4. 12 points possible can be awarded.

Instruction Total Length of Lesson: 50 minutes	
Instructional Procedures	Questions
Set/Introduction Total Time: 5 minutes	

<u>ENGAGE</u> ● When the students enter the class and are seated, the teacher will go over the informational text articles, " so the students have an idea of the purpose for the activity. ● Presenting the Problem through Google Slides ○ Present the "Makerspace Presentation" slideshow to the whole class. ○ Explain that our environment is in a great need for us to start reducing waste, reusing materials, and recycling. ○ Explain to the whole class why we must start taking better care of our environment. ○ The teacher should review personal connections for the students to relate to such as how litter and waste have negative effects on our environment. (Straws and sea turtles, and TVA Kingston ash spill). ○ Present the scenario/ inquiry task: "There is a beach that is in desperate need of trash pick-up. We need to help make this beach clean again by using art and technology to tackle the challenge. Your task is to design and build trash collecting robots."	How much waste do you produce in a week? month? year? Can you tell us about a local environmental problem? What is one thing you can use less of or eliminate completely do to reduce waste? Using the fist to five scale, who understands the task?
Instructional Procedures Total Time: 35 minutes	
Use Headings for each subsection of your procedures and provide a time for each. Add or delete rows as necessary.	
● The teacher will sit out materials prior to class. ● Using the Dash bots and Blocky App ○ The students will view a presentation in which they will learn how to use and code dash bots. ○ Further instructions as to how to use and code the dash bots will be given verbally to the whole class if there is any confusion.	Are there any questions about what you just saw? Who is familiar with the Dash? Blockly program?
<u>EXPLAIN (Will be completed later on throughout the lesson)</u> ● Data Tables ○ The teacher will pass out the data tables. ○ The teacher will go over what is to be recorded in the data tables. ■ Quick Sketch of Design ■ Success of Prototype ○ The teacher will explain that the students are to create two different prototypes of trash collecting robots.	Using thumb positions, how comfortable do you feel completing the data tables?
● Assign Students into Teams ○ Students will work in groups of 5 to 6 in order to solve this task.	

○ The teacher will explain, "Work with one other person in your table group in order to complete this task."	
● Pass out the Paper ○ Pass out the paper to each group. ○ Explain to the students that they will be using their bots to collect trash (tiny, crumpled up pieces of paper and foil) and deposit it in a designated recycling center (a square draw on paper). ○ Explain to the students that they most create a code in which the trash bot moves from each indicated trash spot marked on the beach. ○ Explain to the students that they must	
EXPLORE ● Prototype #1 (15 minutes) ○ Have students use materials and collaborate with their group in order to create prototype #1. ○ Explain to the students that they will have 15 minutes to create, program, and record their results for prototype #1. ○ The teacher will set a timer for 15 minutes. ○ On each paper, with the recycling center drawn on it, the teacher will layout pieces of trash, so that the students are able to create their code. ○ As the students are working, the teacher should be walking around giving suggestions, guiding collaboration, and reminding students to document their work in their data tables. ○ Encourage students that they need to be testing out and revising their programming to see if they can pick up more with changing the direction of the bot to pick up materials. ○ At the 5 minute mark, the teacher will encourage students to record their results for prototype #1 in their data tables if they have not already done so. ○ At the end of the 15 minutes, students will start working on prototype #2.	
ELABORATE ● Protype #2 (10 minutes) ○ Have students collaborate with their group in order to revise prototype #1. ○ Explain to the students that they will have 10 minutes to revise, re-program, and record their results for prototype #2. ○ The teacher should convey that they are not to create a whole new trash bot, just revise prototype #1, such as altering the first code that was made.	

○ NOTE: If the students are struggling to create a successful code, show them the premade code after a few minutes has elapsed. ○ The teacher will set a timer for 10 minutes. ○ As the students are working, the teacher should be walking around giving suggestions, guiding collaboration, and reminding students to document their work in their data tables. ○ At the 5 minute mark, the teacher will encourage students to record their results for prototype #2 in their data tables if they have not already done so.	
Closure Total Time: 10 minutes	
<u>EVALUATE</u> ● CER Template ○ The teacher will first review how the CER template should be completed. ■ Writing in complete sentences, provide your claim, reasoning, and evidence within the boxes. ■ NOTE: If time is limited, the teacher can help the students complete this CER template step by step. ■ Claim: This section should describe <u>which</u> prototype was the most successful **in** helping make the environment a more safe and clean place. ■ Evidence: This section should describe <u>why you determined</u> the particular prototype prototype was the most successful in helping make the environment a more safe and clean place. ■ Reasoning: This section should describe <u>why the particular prototype was the most successful</u> (Modifications, programming, etc.) ■ The teacher should mention to the students that examples are noted on their “CER Template” hand-out. ○ The teacher will pass out CER templates to all of the students. ○ Individually, the students will complete the “CER Template” hand-out. ○ The students will fully complete this CER template before leaving class.	What design was most effective for your trash bot?
● “Scientists say more sea turtles are eating plastic and dying” AND Writing Reflection Prompt ○ The teacher will pass-out the article, “Scientists say more sea turtles are eating plastic and	

dying" and a Writing Reflection prompt to the students at the end of class. ○ The student must first fully read "Scientists say more sea turtles are eating plastic and dying" as well as complete all the reflection questions for homework.	

Adaptations to Meet Individual Needs:

- During the design and redesign process, students will be placed in groups comprised of higher level learners and lower level learners.
- Throughout this process, the higher level learners will serve as a guide and example for the lower level learners.
- The teacher will give clear, repeated, and precise instructions both verbally and posted on the Projector throughout the entirety of the lesson.
- Throughout the entire lesson, the teacher will be circulating.
    - Throughout the design and redesign process, the teacher will make an effort to address each group in order to identify their needs or to be able to expand on instruction.

Management/Safety Issues:

- Before the lesson is taught, the teacher should prepare all materials and tools ahead of time.
- The teacher should prepare and have a management plan for time and instructions to have posted and to be given verbally throughout the lesson.
- The teacher should ensure respect and positive rapport between teacher and student and between students and their fellow peers throughout the design process completed in groups.
- The teacher should ensure that students are staying on-task, engaged, and focused throughout the design and redesign process of constructing their trash bot.
- The teacher should enforce all classroom rules, including safety, throughout the entirety of the lesson and each group activity.

Materials/Resources

Materials

- Labeled
- Dash bots
- Paper with labeled "recycling center" and stars where the teacher should lay the trash
- Presentation
- Materials to Create Trash Bot
    - Spoons and forks
    - Notecards
    - Tape
    - Pipe Cleaner
    - Scissors
    - Paper Plates
    - Stopwatch/timer or can be done through their phone
    - Aluminum foil
- CER Templates
- CER Scoring Rubric
- Data Tables
- Pencils
- Timers
- iPad

- Blockly App
- Calculator
- Trash to Collect - (Cans

Resources:

- Idea for lesson: https://blog.ozobot.com/ozobot/builtwithozoblockly-bot-beach-cleanup/
- Data Table: Personally Created
- CER Templates: Personally Created
- Presentation: Personally Created
- CER Scoring Rubric: https://www.corelaboratewa.org/blog/teacher-leaders/single/~board/teacher-leaders-archive/post/cera-rubrics
- Information Text
    - https://newsela.com/read/plastic-turtles/id/12011/
        - By Washington Post, adapted by Newsela staff
        - Published:09/25/2015
    - https://www.seeturtles.org/ocean-pollution

Rationale/Theoretical Reasoning
Student Challenges/Misconceptions: (Functional misconceptions) Works with tablets, phones, chromebooks, ios operating system Dash is the bluetooth enabled and does not require an internet connection. Dash has a battery life of 90 minutes (Misconceptions of practice) There is only one right way to program the Dash. In fact, creativity in programming is celebrated. We are JUST playing with robots. In fact, creations that are made in play can have long-term benefits for society and the environment. Students should use safe practices such as; avoiding collision with other dash, students, object, etc avoid dropping devices by holding with two hands at the base NEVER the top of the Dash. Computer or tablets should remain on a base when programming.
Rationale / Theory: **TPACK** According to TPACK.org, “At the heart of the TPACK framework, is the complex interplay of three primary forms of knowledge: Content (CK), Pedagogy (PK), and Technology (TK).” Throughout our lesson, we greatly relied on these primary components of the TPACK model to design the lesson for students. This lesson was designed for the students to use technological knowledge. For instance, the students must demonstrate technological knowledge in understanding how to use Dash and Blockly programming software. The lesson was designed for students to demonstrate technological knowledge by using and running the Dash and Blockly programming in order to create a code for the Dash robot to successfully clean the beach. The TPACK model also encourages the teacher to use pedagogical knowledge. For this particular lesson, we greatly relied on the 5E model. The teachers will engage by explaining the scientific phenomena of the real world pollution problem, as it is affecting our local lakes and sea turtles in the ocean. Furthermore, the teacher will be encouraging the students to participate in the 5E model by explaining how they make their various prototype and codes, exploring how they can make revisions to their prototypes and codes, evaluating which prototype type and code was the most efficient, and evaluating the results from their observations and records formally and precisely through the use of a CER template. Furthermore, this lesson was designed for the students to use and demonstrate content knowledge. For instance, by the end of the lesson, students should be able to demonstrate content knowledge by being able to convey and explain pollution issues and environmental factors in the subject of science. Reference: http://tpack.org/

SAMR
The SAMR model is used throughout our lesson. We mostly use modification and redefinition. Students will use the Dash robot, paired with the Blockly app, as a direct tool for students to demonstrate understanding of coding and pollution problems. They should then be able to explain the reasoning behind their codes and why that is the most efficient way to reduce pollution. Instruction for this lesson allows students to use technology for the delivery and demonstration of content. They can also use the technology to problem solve and implement practices that could be shared on a public/privately shared platform. The use of the dash and the app for programming can give students a real world idea of how to approach a problem that would be inconceivable in the classroom otherwise.
Reference: SAMR Model hand out, page 5 in our technology folder

Defining Computational Thinking for Mathematics and Science Classroom tells us that computational programming and problem solving allows students to explore scientific and mathematical phenomena using computational abstractions. This helps learners develop deep understanding through the building of an algorithm for problem solving with a focus on efficiency. Students will be able to practice decomposing problems into subproblems so that the problems can be reframed as solvable or at least progressable toward solution with the use of the computational tool.

CT in Math and Science Taxonomy lists *troubleshooting and debugging* in the “Computational Problem Solving Practices Category” and this will be observed as students make revisions for their final program. Without this step, there will be no progress toward efficiency.
Modeling and Simulation Practices are being used here to help students gain access to concepts that are large in scale. The concept of environmental remediation is a daunting task for experienced engineers and oceanographers but with the use of programming, students can design, assess and build *models* that could possibly be used for the phenomena. Students will need to *collect and analyze data* that is gathered from blockly program. This analyzation will be done by *visualizing information* about the route to efficient beach clean up.
Reference:
(Journal of Science Education and Technology. October 2015. David Weintrop)

Maker Lesson Summary

Lesson Title	Beach Cleanup DASH
Primary Maker Lesson Tool Used	Dash
Names of collaborators	
Subject(s) and grade level	Science - 5th grade

Lesson Description: (*Give a brief synopsis of what took place in your lesson*)

The Beach Cleanup Dash lesson was used to incorporate STEM, robotics and coding to solve real-world issues. The students reviewed pollution in our surrounding areas (Kingston ash spill, sea turtles and plastic straws), and were given the task to sketch and make a prototype to efficiently collect trash on the "beach" and deliver it to the recycling bin. The students not only had to sketch and build, they then had to program their dash bots to successfully go from the starting line to the two required destinations (trash pick up and recycling bin). After they ran their first code with their first prototype, they had a chance to make modifications and compare how many pieces of trash they collected with each prototype.

Lesson Implementation: (*Where did you teach your lesson, description of class, students, etc***.)**

The lesson was taught at __ Middle School in 5th grade science classes. This lesson was carried out for a total of 3 class periods. The class sizes ranged from around 23 to 28 students per class. The students within all three of these classes were not separated by ability level. For instance, within each class, we were teaching to groups of students who had multiple ability levels.

Connection to important concepts and skills within the discipline and/or across subject areas: (*Describe the main content that you were teaching for all that apply. Refer to your selected standards in your plan and the theory/rationale of your plan as needed.)*

Science:5. ETS1: Research, test, re-test, and communicate a design to solve a problem.

5. PS1. 2: Analyze and interpret data to show that the amount of matter is conserved even when it changes form, including transitions where matter seems to vanish.

5. PS2. 2: Make observations and measurements of an object's *motion* to provide evidence that a pattern can be used to predict future motion.

Math: measurement, multiplication, addition,

Computational Thinking Skills: Modeling and simulation skills were the focus of this lesson.
Students had the opportunity to think about how they might help to remediate environmental problems.
Students used debugging and troubleshooting throughout their programming with Blockly. They needed to do this to be efficient. Students who did not use a ruler to measure distance did more troubleshooting than others.
Those students relied on visualizing rather than close analyzation

Other: Social studies concepts were mentioned briefly when we used a current or near historical event to make pollution problems more relevant and personal (Kingston Coal Ash Spill).

Connecting to the SAMR Model

Explanation: https://www.schoology.com/blog/samr-model-practical-guideedtech-integration

What level of the SAMR model do you feel your enacted lesson reached? Why? (*Refer back to what you included on your lesson plan as needed)*

The SAMR model is used throughout our lesson. We mostly use modification and redefinition. Students will use the Dash robot, paired with the Blockly app, as a direct tool for students to demonstrate understanding of coding and pollution problems. They should then be able to explain the reasoning behind their codes and why that is the most efficient way to reduce pollution. Instruction for this lesson allows students to use technology for the delivery and demonstration of content. They can also use the technology to problem solve and implement practices that could be shared on a public/privately shared platform. The use of the dash and the app for programming can give students a real world idea of how to approach a problem that would be inconceivable in the classroom otherwise.

Reflection:

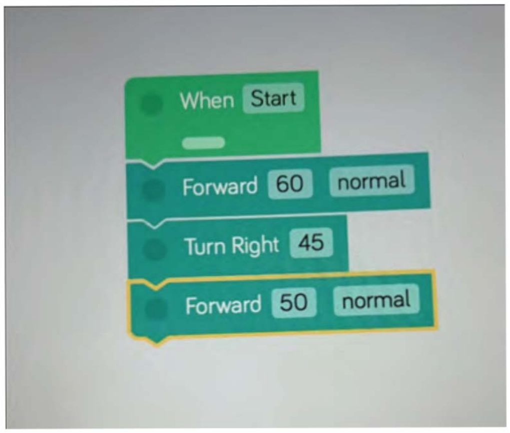
What Went Well? (*Be thorough - give specific examples)*

Throughout the lesson, we can reflect on several things that went well. For instance, we were successful in the way in which we were prepared and organized to carry out the lesson with each group. We had several materials and tools that we were responsible for using and setting-up before each lesson for each class to use. Furthermore, we were successful in the way in which we were able to explain the real world phenomena to each class. By successfully describing pollution issues such as sea turtles and how they are in danger due to pollution, as well as the TVA ash spill, we were able to successfully engage students to want to solve the task at hand. Additionally, we had several instances in which we had to handle disagreements and communication issues, as the students struggled to come agree upon group designs for their trash bots. We were successful in the way in which we were able to handle these disagreements and communication issues.

What would you change? (*Be thorough - give specific examples & explain why.)*

There should be smaller groups with defined roles. The groups were large and some were not engaged. Some others were adamant that a specific task should be relegated to them. This caused students to distract other team members. With smaller group sizes, the roles would be spread out more evenly, and there would be less down time for each student. The only other change I would make is class time provided. This needs to be done with a school that is on block schedule so there is at least 90 minutes for the class.

Pictures of students working, student artifacts and/or links to video:


When Start
Forward 60 normal
Turn Right 45
Forward 50 normal

Part 2

Name:	Date: 12/09/19
Lesson Topic: Building Animal Habitats	Grade Level:4th

Curriculum Standards

TN Science Content Standard:
4.ETS2 1. Use appropriate tools and measurements to build a model. 2. Determine the effectiveness of multiple solutions to a design problem given the criteria and constraints.

4.ETS1: 1. Categorize the effectiveness of design solutions by comparing them to specified criteria for constraints.

2.LS2: 1. Develop and use models to compare how animals depend on their surroundings and other living things to meet their needs in the places they live. 2. Predict what happens to animals when the environment changes (temperature, cutting down trees, wildfires, pollution, salinity, drought, land preservation).

Component Idea(s):
- A. Interdependent Relationships in Ecosystems
- A. Interdependence of Science, Engineering, and Technology
- C. Optimizing the Design Solution

Math
- **4.MD.A.1** Measure and estimate to determine the relative sizes of measurement units within a single system of measurement involving length, liquid volume, and mass/weight of objects using customary and metric units.
- **4.MD.A.3** Know and apply the area and perimeter formulas for rectangles in real world and mathematical problems. For example, find the width of a rectangular room given the area of the flooring and the length, by viewing the area formula as a multiplication equation with an unknown factor.

TN Digital Readiness Standards
- **CC.3** Contribute, individually or as part of a team, to work to identify and solve authentic problems or produce original works using a variety of digital tools and devices.
- **4.CCP.1** Recognize the input and output devices along with the components that form an interdependent system with a common purpose.

Science and Engineering Practices:
- Developing and Using Models
- Constructing explanations and designing solutions
- Using Mathematical and Computational Thinking
- Obtaining, evaluating, and communicating information

Crosscutting Concepts:
- System and System Models
- Structure and Function
- Scale, Proportion, and Quantity

Central Focus: Habitats

Central Focus Statement: What animals need to survive in their habitats. Designing and constructing models of those needs in TinkerCAD, and staying within the limits of the 3D printing bed.

Real-World Phenomena:
- Flat grasslands are habitats for rabbits, elephants, lions, zebra, etc.
- Cold, Arctic environments are habitats for polar bears, penguins, and seals
- Trees with lots of shade are habitats for birds, squirrels, monkeys, etc.

3-Dimensional Lesson Objectives (or Multi-dimensional)

The learner will..

● Describe and reflect on the environment and the basic needs of plants and animals, and what elements are needed to survive in their habitat. ● Design and construct a model of a habitat suitable for an assigned animal within the measurement constraints in TinkerCAD ● Solve basic measurement and metric conversions to better understand assignment constraints

Language Demands		
	Word(s) or Descriptions	Supports
Language Function	● Students will be able to **describe** what elements of a habitat an animal needs to survive ● Students will **justify** why their habitats are suitable for their assigned animals	● Teacher modeling (guiding questions) ● Class discussion ● Think-Pair-Share
Subject-Specific Vocabulary (Tier 3)	Criteria, Constraints, Print bed, Filament TinkerCAD 3D Printer	● Teacher modeling (introduction) ● Powerpoint Introduction ● Class discussion ● Exit Ticket
General Academic Vocabulary (Tier 2)	Measurement Centimeter Millimeter Habitat Shelter Food Source	● Teacher modeling ● Powerpoint introduction ● Class discussion ● Tinkering with Habitats Handout ● Exit Ticket
Syntax	● Students will use their design to measure each part of their habitat model not exceeding the TinkerCAD limits. ● Students will document their measurements on their design model for each side to help them prepare for designing in TinkerCAD.	● Students will be able to use the powerpoint presentation to help them understand how to design and use TinkerCAD for their assignment given. ● Teacher modeling
Discourse	● Students will engage in discourse by working in teams and planning their habitat models.	● Students can use the powerpoint slides to help them understand the instructions of TinkerCAD and design their models. ● Teacher modeling

Assessment/Evaluation
Formative

Connected Objective(s)	Name & Description	Evidence Collected of Student Understanding	Location in the Lesson
• Describe and reflect on the environment and the basic needs of plants and animals, and what elements are needed to survive in their habitat. • Design and construct a model of a habitat suitable for an assigned animal within the measurement constraints in TinkerCAD • Solve basic measurement and metric conversions to better understand assignment constraints	**Thumbs up and thumbs down**. After the powerpoint and handout is completed the students will respond with a thumbs up meaning they fully understand, a thumbs down meaning they do not understand and a thumbs in the middle meaning they partially understand.	The teacher will be able to see the students understanding by them giving a thumbs up or down when prompted during the review/ presentation.	During the presentation slides and handout review
	Observation: Teacher will observe students responding to questions in class as well as observing their group discussions on what part of their habitat they are creating in TinkerCAD	The teacher will be able to see the students understanding by observing their responses to any questions given in the class as well as the group discussion on designing and creating their models to use in the 3D printer.	During the presentation as well as the designing and constructing the student habitat models.
	Informal Questioning: Teacher will observe students responding to questions during the question/answer discussion prior to designing and constructing their habitat models.	The teacher will be able to see the students understanding by observing their responses to any questions given during the informal questioning.	Questions and discussions before designing models
Summative			
Connected Objective(s)	Name & Description	Evidence Collected of Student Understanding	Evaluation Criteria
• TLW solve basic measurement and metric conversions to	**4.ETS2 1. Exit Ticket** Students will reflect on TinkerCAD and their experience with working	Evidence of student understanding will be collected during the time allotted for exit ticket	Student understanding will be revealed through correctly answering the

better understand assignment constraints ● TLW construct a system and system model using TinkerCAD that will be suitable for assigned animal with a team	with it. Students will describe the process of working together as a team and their role in that team. Students will be asked to reflect on, when working with TinkerCAD, what was easy for them to grasp and what was more difficult. Students will also show further understanding of basic metric conversions.	completion. The teacher will walk around and observe how students respond to exit ticket questions. Evidence will also be collected through the collection of the exit ticket and reading over student's responses of understanding.	metric conversion questions. Most of the questions on the exit ticket are opinion-based and opportunity for student reflection.

Instruction Total Length of Lesson: 90 minutes	
Instructional Procedures	Questions and Actions
Set/Introduction Total Time:10 minutes	
Discuss habitat Project (2 minutes) (h) ● The teacher will connect and introduce habitat project and emphasize that students should already be assigned an animal. **Review of centimeters and millimeters (5 minutes) (s)** ***Slides 1 - 4 *** ● After distributing Tinkering with Habitats Handout, the teacher will go over the measurement review questions at the beginning. ● The teacher will orally go over the answers to the review measurement conversions with students while students fill in the answers on their sheet. ● The teacher will emphasize that the TinkerCAD design needs to be *smaller* than 10x10x10cm, which is why review is necessary **Briefly Introduce 3D Printing and TinkerCAD (3 minutes) (h)** ● The teacher will quickly introduce TinkerCAD by telling them they will use an online program to design 3D printable objects and pass around different examples of 3D printed objects that had been done prior.	1. How many millimeters are in a centimeter? 2. How many millimeters are in 10 centimeters? 3. The design needs to be smaller than what measurements in millimeters? 100 x 100 4. What part of the habitat are you creating?
Instructional Procedures Total Time: 60-65 minutes	
Use Headings for each subsection of your procedures and provide a time for each. Add or delete rows as necessary.	
Designing a habitat for assigned animal (10 minutes) **(s)** ● The students will use this time to come together as a team and begin designing their habitat on paper (Tinkering Handout) ○ Each student should select one of the following: Food source, Water Source, structure/shelter, or animal to design. (*If more than 4 students are in a group, additional students can design more food*.) ○ Students should use rulers and add dimensions to their sketches. They should plan logically so that no component is larger than 10x10x10cm and the individual components fit within these dimensions. ● The teacher will walk around and monitor the student discussion and designing process. Teachers will approve sketches prior to beginning next step.	1. What are the parts of your habitat? 2. What are you responsible for creating?

Powerpoint Presentation (2 minutes) Slide 5 **(h)** ● The teacher will begin by asking guiding questions of past experiences students may have had with 3-D printing, TinkerCAD, or something similar like Minecraft. ● The *students* will raise their hands in response to the guiding questions	1. Has anyone ever 3-D printed anything before? If so, what? 2. Have you ever used Minecraft? 3. Do you guys have questions before we begin with TinkerCAD?
TinkerCAD class house creation (18 minutes) Slide 6-11 **(s)(h)** ● Students will be asked to open their computer and go to TinkerCAD.com ● From there, students will choose “Join Now!” and then “Students, join a class” ● The teacher will display and orally project the class code for everyone to log in and join ● After joining the class, the students should see their open work-plane on TinkerCAD ● **At slide 11 The teacher will begin projecting the example of designing a house with the students on tinkercad.com** ● The students will mimic the teacher’s actions of creating and designing a house. ○ Pull out a block and model resizing ○ How to determine dimensions ○ Model making objects hollow and adding a hole ○ Model scribble feature ○ grouping and ungrouping ○ Introduce controls: moving workplane, how to resize, making sure design is *on* workplane (not above or below) ● Explore menus to see what shapes they can build with.	1. What shape should we use for a house? 2. What shape should we use for a window? 3. What shape should we use for an animal? 4. *This* is where you find: a. 3-D shapes b. Dimensions c. How to insert a hole d. How to move your design around (ctrl + move mouse) e. How to change design height/width
TinkerCAD habitat designing (40 minutes) **(s)(h)** ● At this time, students will be asked to take the habitat design on paper and try their best and create it into TinkerCAD. ● The teacher will instruct each student to begin tinkering their design for their habitat in TinkerCAD on their own computer. ● The teacher will walk around and monitor student progress on their design as well as monitoring that students are staying on target with their assigned task.	1. What part of the habitat are you responsible for designing? 2. What shapes are you wanting to use for your design? 3. What measurements are you using for your design?
Closure Total Time:10 minutes	
(s)(h) ● Students will be asked to submit/save their designs and close their computers. ● The teacher will ask students to take their Tinkering with Habitats handout and turn it over to the Exit Ticket on the back. ● Students will fill out the exit ticket in full and turn it in when they are finished. ● Lastly, an appointed teacher will decide which group has the best habitat that will be printed using the 3D printers in class.	1. Everyone please save what you have of your design and close your computers. 2. Please fill out the exit ticket in full and turn it in when you are finished. 3. Closing question: What is one thing you learned about TinkerCAD or 3-D printing today?
Adaptations to Meet Individual Needs: ● Pair inclusion students in appropriate groups who have a higher understanding of the content.	
Management/Safety Issues:	

● Monitoring the students use of computers and appropriate behaviors. ● Be Responsible using technology devices.
Materials/Resources
● Computers per group ● Lesson and animal plan from previous lesson in class ● TinkerCAD registration and class preparation ● Nicknames from TinkerCAD for the students ● Rulers ● Google Slide presentation ● Tinkering with Habitat Handout ● 3D printed samples

Rationale/Theoretical Reasoning
Student Challenges/Misconceptions: ● Milimeters are smaller than centimeters, therefore the number of millimeters in a centimeter should be smaller. ● TinkerCAD/3-D printing beds do not have limitations; restrictions aren't important in the design process
Rationale / Theory: **TPACK -** Through this lesson, we have several components of the TPACK and SAMR Models integrated. A main one that is integrated is **Technological Pedagogical Knowledge** through the introduction of TinkerCAD and how to use it. We will have an introduction PowerPoint that will introduce TinkerCAD's basic components and how to use them. We will also be using materials, such as, a Smartboard, to project this introductory slideshow. **Technological Content Knowledge** is also integrated through the use of a Smartboard, the class set of laptops, TinkerCAD, and a 3-D printer to teach the scientific content of animal habitats. Through the integration of these types of technology, students will be given an alternative way to learn about how certain habitats are suitable for certain animals.This could also be categorized as simply **Technological Knowledge** as well. **Pedagogical Knowledge and Pedagogical Content Knowledge** can also be found through the use of direct instruction in the introduction of TinkerCAD and how to use it. Also, throughout the entire lesson, we are integrated Inquiry-based instruction through the use of this computer program and a 3-D printer. Also, we will be using phenomenon to inspire student's creativity of creating their animal and a suitable habitat. **SAMR -** Through this lesson, we are **redefining** ways students learn about the components of a certain habitats and their effect on animals that live there. Through the use of the program, TinkerCAD, it allows for creation of new tasks that previously would be inconceivable. For example, students will begin by brainstorming a habitat and its component for an animal they have chosen, and through the designing process in TinkerCAD, this learning can be created three-dimensionally. Students can actually physically see and hold their creations when printed on a 3D printer, and see how they work together to serve the purpose of a habitat. **CT in Math and Science Taxonomy:** Referring to the "computational thinking in mathematics and science taxonomy" chart, for **Data Practices** throughout this lesson, students will be **visualizing and manipulating data** by visualizing their habitat through pencil and paper, as well as, through technology. Students will manipulate data by changing and working with dimension limitations of their habitat. For **modeling and simulation practices,** students will be **designing and constructing computational models** by physically drawing out the part of the habitat that they will be creating, as well as, constructing their design through TinkerCAD. For **Computational Problem Solving Practices,** students will be **developing modular computational solutions,** by actually designing their habitat/or component of one in TinkerCAD. Also, students will be **troubleshooting and debugging** by the thinking-process of how components of the habitat are going to fit together and follow dimension limitations. For **Systems Thinking Practices,** students will be **communicating information about a system** by working in their groups and assigning components within their habitats. Also, students will be **investigating a complex system as a whole** by discussing how their components will all come together to make a suitable habitat for their assigned animal.

References

TPACK -

SAMR -
Defining Computational Thinking for Mathematics and Science Classrooms, by Weintrop, et.al
https://ccl.northwestern.edu/2015/Weintrop%20et%20al.%20-%202015%20-%20Defining%20Computational%20Thinking%20for%20Mathematics%20an.pdf

Maker Lesson Summary

Primary Maker Lesson Tool Used	TinkerCAD
Names of collaborators	
Subject(s) and grade level	4th grade Science

Lesson Description: (*Give a brief synopsis of what took place in your lesson*)

Our lesson for 4th Grade at __ Elementary School was an introduction to the program, TinkerCAD. We began the lesson with a brief review of the metric system and the differences between centimeters and millimeters. This review would allow students to better understand the limitations of the printer bed and how to accommodate accordingly. Next, we introduced what the program actually looks like and where to find the basic controls throughout it (i.e., basic shapes, how to move the workplane, how to change measurements, etc.). We walked the students through and introduced how to create a “house” in the program and where to find the materials needed to do so. After we had briefly introduced the program, we gave the student’s their assignment for creating a habitat that was suitable for their animal. Some students were quick to understand and begin working through the program and building their habitat or piece to their habitats. Other students had difficulty with managing the controls and how to productively create their habitats.

Lesson Implementation: (*Where did you teach your lesson, description of class, students, etc***.)**

We had 87 students total split into two rooms. The students were grouped into groups of 3-5 students. Each group worked independently on designing their habitats on their paper, measuring their designs based on the constraints in TinkerCAD, and designing their models in the program.

Connection to important concepts and skills within the discipline and/or across subject areas: (*Describe the main content that you were teaching for all that apply. Refer to your selected standards in your plan and the theory/rationale of your plan as needed.)*

Science: TN Science Content Standard:

4.ETS2 1. Use appropriate tools and measurements to build a model. 2. Determine the effectiveness of multiple solutions to a design problem given the criteria and constraints.

4.ETS1: 1. Categorize the effectiveness of design solutions by comparing them to specified criteria for constraints.

2.LS2: 1. Develop and use models to compare how animals depend on their surroundings and other living things to meet their needs in the places they live. 2. Predict what happens to animals when the environment changes (temperature, cutting down trees, wildfires, pollution, salinity, drought, land preservation).

The students were learning about habitats and what animals need to survive in their habitats. The teacher had previously discussed with them habitats and they were building habitats with candy and other items. For our lesson, we came into the classroom to review with the students about habitats and what animals need to survive such as a food source, water source, and a structure/shelter. The students were walked through each step in how to open TinkerCAD and log in with their own personal information. We taught the students about how to use the program, how to build, connect pieces, make hollow sections etc. The students were given time to do their own designs on paper. The students each had a part of the habitat to draw and design. Once the students drew their designs, they measured their designs and used those measurements in TinkerCAD when designing their models based on the constraints of TinkerCAD measurements.

Math:

- **4.MD.A.1** Measure and estimate to determine the relative sizes of measurement units within a single system of measurement involving length, liquid volume, and mass/weight of objects using customary and metric units.
- **4.MD.A.3** Know and apply the area and perimeter formulas for rectangles in real world and mathematical problems. For example, find the width of a rectangular room given the area of the flooring and the length, by viewing the area formula as a multiplication equation with an unknown factor.
- Students also had to convert basic measurements from centimeters to millimeters and back.

The students had to take ideas that they had previously thought about that included taking an animal and making a structure for the animal to live in, a food source, and a water source so that animal could survive. Students had restrictions on how big their design could be. The students had to take their designs and convert the measurements to millimeters and centimeters to make sure that their design would be accepted. The students also had to know how to recognize basic shapes.

Computational Thinking Skills:

- **CC.3** Contribute, individually or as part of a team, to work to identify and solve authentic problems or produce original works using a variety of digital tools and devices.
- **4.CCP.1** Recognize the input and output devices along with the components that form an interdependent system with a common purpose.

The students had to work together as a team to make sure that they made all of the things that the animal would need to survive. The students also needed to work individually to design their part of the habitat for the animal. The students used shapes and other online tools to design their part of the habitat that their animal needed.

Connecting to the SAMR Model

Explanation: https://www.schoology.com/blog/samr-model-practical-guideedtech-integration

What level of the SAMR model do you feel your enacted lesson reached? Why? (*Refer back to what you included on your lesson plan as needed)*

Through this lesson, we were **redefining** ways students learn about the components of a certain habitats and their effect on animals that live there. Prior to the introduction of TinkerCAD, students were asked to brainstorm their habitats through the use of various Through the use of the program, TinkerCAD, it allowed for the creation of new tasks that previously would be inconceivable. We began by asking students to brainstorm a habitat and its component for an animal they have chosen, and through the designing process in TinkerCAD, this learning is created three-dimensionally. As soon as we get these designs printed, students can actually physically see and hold their creations and see how they work together to serve the purpose of a habitat suitable for their animal.

Reflection:

What Went Well? (*Be thorough - give specific examples)*

S: I think the lesson plan went well in using the powerpoint to explain to the students about measurements and using TinkerCAD. It was able to keep us on track and follow our plan to make the lesson successful. I think the students had a lot of fun tinkering with their models and designing their habitats. I only seen two students get frustrated and upset. Most of the students were very creative and jumped right in. I enjoyed seeing how creative they could be since they had never used the program before.

H: Overall, I think our lesson went well. I think, for the majority, the students got a good grasp on TinkerCAD and the basics of the program. Some students looked at this opportunity to express their creativity and show what kinds of cool habitat items that they could create. Some students even went as far as creating a *whole* habitat rather than just a component of one. Also, students really enjoyed seeing the 3-D examples that we brought in for them to look at and hold. I thought this really put TinkerCAD into perspective and show them what their designs would look/feel like if they were printed.

B: I thought the lesson went well for the circumstances that were presented. The students did a great job with dragging and dropping on tinkercad. The students listened well and logging on was not as difficult as I thought it would be.

What would you change? (*Be thorough - give specific examples & explain why.)*

S: I would have changed the time limits for the students. I would have given them more time to spend in TinkerCAD creating their models to print. I believe combining two classrooms into one was ok, but there were only two of us in the room who were experienced with the program trying to help 45 students and teachers understand how to use certain features. Some of the students did not finish their designs. I also think the lesson would have went better if it was not right at the end of the day. The students were very interested in learning about the designs and seeing what we brought, but I felt like we were rushed.

H: If I were to change anything of this lesson, I would also have to say the time limitations. More time was definitely needed for the students to work on their designs and express their full creativity through their habitats. I felt like the time limitation put pressure on a lot of students to put something together and finish. For example, some students only put together one, basic component of a habitat, like a ball for a toy, instead of building upon that creatively. Also, because of the lack of time, we were not able to finish and allow student's time for completion of the exit ticket, or our summative assessment. With more time, it would have allowed students to complete that and give us, as teachers, more insight of how the students felt about the program.

B: If I had anything to change I would change the time that we had to do everything. I feel like this lesson may have been better over a two day time rather than just an hour and a half. I also would have changed the amount of students in each class. It was difficult to try to get to every student because students were everywhere. In the end I believe the students received a concept of what tinkcad is and hopefully it'll be easier for them in the future.

Appendix D
Computational Thinking Survey

Multiple Choice Prompts (Rich et al., 2017) (*Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree*)

Teaching CT self-efficacy

1. I can explain basic programming concepts to children (e.g., algorithms, loops, conditionals, functions).
2. I know where to find the resources to help students learn to code.
3. I can find applications for coding that are relevant for students.
4. I can integrate coding into lessons I teach.
5. I can help students debug their code.

Open-ended Prompts (Yadav et al., 2011)

1. In your view, what is computational thinking?
2. How can we integrate computational thinking in the classroom?
3. How does computational thinking relate to other disciplines and fields? Please provide specific examples.

Rich, P. J., Jones, B., Belikov, O., Yoshikawa, E., & Perkins, M. (2017). Computing and engineering in elementary school: The effect of year-long training on elementary teacher self-efficacy and beliefs about teaching computing and engineering. *International Journal of Computer Science Education in Schools, 1*(1), 1-20.

Yadav, A., Zhou, N., Mayfield, C., Hambrusch, S., & Korb, J. T. (2011, March). Introducing computational thinking in education courses. In *Proceedings of the 42nd ACM technical symposium on Computer science education* (pp. 465-470).

Appendix E
Participant Views of CT and Applications in the Classroom

Pre-Survey				
	Participant A	**Participant B**	**Participant C**	**Participant D**
View of CT Theme	The use of computers	Process of solving problems	Process of solving problems	Process of solving problems
View of CT Statement	The knowledge and mindset that one has in order to be able to operate and manage computers.	The thinking that provides an answer or result, it is the solving procedure.	Being able to problem solve using skills other than just textbooks	Being able to think in a process or a working strategy. It is the understanding or the want to understand how something works or operates
How to Integrate CT in the classroom	Having our students do computer-based projects, use a variety of software.	In every way! Asking students to make connections between ideas is computational thinking.	Using technology, providing problems that need to be solved (not just math, but like real-world), etc.	Adding coding into the classroom
Post-Survey				
	Participant A	**Participant B**	**Participant C**	**Participant D**
View of CT Theme	The use of computers	Process of solving problems	Process of solving problems *with* a computer	Process of solving problems *like* a computer
View of CT Statement	The thought process in which an individual uses in order to use, manage, and understand how to use different forms of technology	The use of concepts to solve problems.	Solving a problem using computer-based resources.	Thinking in such a way that a computer would. For example, problem-solving methods. It is where there is an input (i.e., problem or scenario) and there is an output.
How to Integrate CT in the classroom	Using different makerspace stations, computer software, and coding apps and programs.	Students should already be using procedural thinking to solve problems but we can get them to see that those steps/ thoughts are strings of code	At OSHS STEM night, they had a Z-SPACE lab that was hands-on, 4D learning that allowed them to troubleshoot issues and learn (like human heart, putting together robots, etc.).	Including lots of different technologies for students to explore and use. Also, teachers could simply give students problem-solving practice in ways that a computer might think or solve.

Appendix F
Lesson Plan Rationales

Part 1 - Rationale for Tinkercad Lesson Plan

Rationale for 4th grade lesson Building Animal Habitats with Tinkercad

TPACK - Through this lesson, we have several components of the TPACK and SAMR Models integrated. A main one that is integrated is **Technological Pedagogical Knowledge** through the introduction of TinkerCAD and how to use it. We will have an introduction PowerPoint that will introduce TinkerCAD's basic components and how to use them. We will also be using materials, such as, a Smartboard, to project this introductory slideshow. **Technological Content Knowledge** is also integrated through the use of a Smartboard, the class set of laptops, TinkerCAD, and a 3-D printer to teach the scientific content of animal habitats. Through the integration of these types of technology, students will be given an alternative way to learn about how certain habitats are suitable for certain animals. This could also be categorized as simply **Technological Knowledge** as well. **Pedagogical Knowledge and Pedagogical Content Knowledge** can also be found through the use of direct instruction in the introduction of TinkerCAD and how to use it. Also, throughout the entire lesson, we are integrating Inquiry-based instruction through the use of this computer program and a 3-D printer. Also, we will be using phenomenon to inspire student's creativity of creating their animal and a suitable habitat.

SAMR - Through this lesson, we are **redefining** ways students learn about the components of a certain habitat and their effect on animals that live there. Through the use of the program, TinkerCAD, it allows for creation of new tasks that previously would be inconceivable. For example, students will begin by brainstorming a habitat and its component for an animal they have chosen, and through the designing process in TinkerCAD, this learning can be created three-dimensionally. Students can actually physically see and hold their creations when printed on a 3D printer, and see how they work together to serve the purpose of a habitat.

CT in Math and Science Taxonomy: Referring to the "computational thinking in mathematics and science taxonomy" chart, for **Data Practices** throughout this lesson, students will be **visualizing and manipulating data** by visualizing their habitat through pencil and paper, as well as, through technology. Students will manipulate data by changing and working with dimension limitations of their habitat. For **modeling and simulation practices,** students will be **designing and constructing computational models** by physically drawing out the part of the habitat that they will be creating, as well as, constructing their design through TinkerCAD. For **Computational Problem Solving Practices,** students will be **developing modular computational solutions,** by actually designing their habitat/or component of one in TinkerCAD. Also, students will be **troubleshooting and debugging** by the thinking-process of how components of the habitat are going to fit together and follow dimension limitations. For **Systems Thinking Practices,** students will be **communicating information about a system** by working in their groups and assigning components within their habitats. Also, students will be **investigating a complex system as a whole** by discussing how their components will all come together to make a suitable habitat for their assigned animal.

Part 2 - Rationale for Lego WeDo 2.0 Lesson Plan

Rationale for 4th grade lesson, Volcano Alert with Lego WeDo 2.0

TPACK: TPACK emphasizes the kinds of knowledge that lie at the intersections between three primary forms: Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK), and Technological Pedagogical Content Knowledge (TPACK). In our lesson we used technological content knowledge by showing knowledge of the legos and applying it to our science lesson. We used the legos to show how scientists are able to look at volcanoes and study them and their eruptions. We also used pedagogical content knowledge by implementing the 5e model, phenomena, and the SEP's into our lesson. Our lesson went in through the phases to engage students, explore the task, explain the importance of the task, elaborate on why they did the task, and evaluated what the students took away. Our lesson plan also had real world phenomena by referencing an article about volcanoes in Hawaii. The lesson also was made using the Science and Engineering Practices. The lesson includes engaging in argument from evidence and using mathematical and computational thinking. The lesson also implemented technological pedagogical knowledge by having knowledge of using a technology enhanced learning environment.

SAMR: In our lesson we demonstrate augmentation by using technology as the direct tool. Originally students would have the building instructions on paper in front of them on paper. Using technology allows for students to have the building instructions step by step in front of them on the Ipad. This makes seeing the steps easier for the students. We also demonstrate modification by using robots. This is using the technology as a significant task redesign. So, Instead of replacement or enhancement, this is an actual change to the design of the lesson and its learning outcomes. The volcanic alarm robot is something that students would not otherwise get to experiment without the use of technology.

CT in Math and Science Taxonomy:

Modeling & Simulation Practices- My students are using computational models to understand a concept by using the ipads and robots to learn more about the standard they are working on. The model will show them how a volcano alert can be used to warn the citizens of the town of the nearby volcano.

Computational Problem Solving Practices- My students are using programming by having to set up the legos by the ipads' apps instruction. They will also be using programming by coding to make their robot move accordingly. They will also be assessing different approaches/solutions to a problem by having to figure out the code to make the robot go back from the green light to the red, they are already given the code to make it go from red to green.