STEMACES Summer Institute

Evaluation Report

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Introduction

STEMACES is a project focused on delivering materials to help 8th graders understand how science is done in the real world. The intervention includes 1) six hands-on engineering and coding activities focused on science content, 2) professional learning facilitated through an in-person summer institute and online Zoom sessions throughout the school year, 3) ongoing support provided by a team from universities located near the implementation sites (SSU and ASU), and 4) the materials necessary for a class to implement the activities.

The LbyM platform consists of an engineering breadboard with an Arduino (together referred to as the BasicBoard) connected to a web-enabled computer running a browser-based application (Web App). The Web App is a LOGO-based programming environment with predefined but modifiable scripts for each task students are expected to complete within the STEMACES activities. The materials kit includes connecting wires, LEDs, and sensors (light, temperature, ultrasonic).

The Summer Institute targeted teacher development of computational thinking skills and technological skills in order to support their effective implementation of the activities in their classrooms. The STEMACES PL team used the *Computational Thinking in Mathematics and Science Taxonomy* (Weintrop et al. 2016)) and the *Technological Pedagogical Content Knowledge* (*TPACK*) framework, developed by Mishra and Koehler (Mishra and Koehler 2006) as guides while carefully designing activities and selecting strategic facilitation moves.

We observed STEMACES Summer Institutes in San Angelo, Texas from July 5-9 and in Rohnert Park, California from July 21-25. Our observations focused on how the activities and facilitation moves supported teacher development in these frameworks.

After attending the Summer Institutes, participants completed a satisfaction survey. Some participants were pilot teachers (some experience with STEMACES activities) and some were new to STEMACES. We did not differentiate these in the survey. There are responses from nine Texas participants and four California participants.

In this report, we first describe the activities, then describe the order in which they were implemented at each site, and finally identify key findings around computational thinking, TPACK, and facilitation based on our observations and the survey.

Description of Activities

In order to develop technological knowledge (TK) about the LbyM platform, participants engaged in different types of challenges. Several of the tasks were based on the student activities teachers will implement in their classroom; these were adult versions and contained less structure and virtually no scaffolding. Tasks that were not based on student activities were designed to deepen content knowledge (CK) and/or pedagogical knowledge (PK) of participants.

For more details about the order and time spent on individual activities see Table 1 and Appendix A.

Engineering Design Challenges

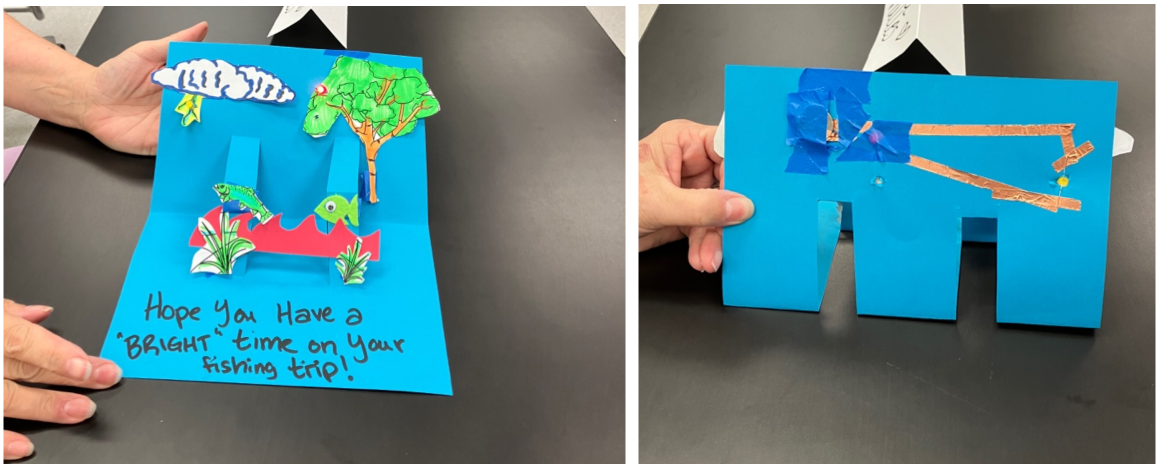
In this PL and in the STEMACES student activities, engineering design challenges are used to introduce key engineering skills that scientists use in the course of their work; these include design and development of a product to meet criteria and within constraints and the use of component datasheets as resources during this process.

Each engineering design challenge (EDC) includes a high-level description of the product being designed, available materials, criteria, constraints, and tips for success. The products being built are sequenced so that the participants build successively more complicated products until they end with a system that can be used to collect data during a science investigation.

EDC: Making an Interactive Card

Participant groups are invited to design and construct a memorable, interactive card to introduce themselves and an assigned ecosystem (Tropical Island, River Valley, Desert). The criteria for the card are that it must have a pop-up feature and a light-up feature. There are art supplies available, and each group also has 1 LED, a 3V coin battery, and copper tape.

Figure 1: Interactive Card



This activity requires basic understanding of creating a circuit and hopefully activates participant prior knowledge. During the debrief, participants discuss how their own process was reflected by the process modeled in *An Engineering Design Process*.

EDC: Connectivity Tester

In order to understand what their design is supposed to accomplish; participants first use a manufactured connectivity tester to evaluate which materials caused the light to turn on. They then use a breadboard, LED, jumper wires, and battery to design and construct a functioning connectivity tester. The sole criterion is that the LED must light up when the tester is connected to a material that conducts electricity. The two tips for success are 1) a reminder that both batteries and LED have polarity and must be connected in the right way and 2) that the circuit must have a complete path from one pole of the battery to the other.

This activity requires a basic understanding of creating a circuit and the ability to identify conductive materials. It is meant to familiarize participants with the structure of the breadboard. They are also introduced to electronics datasheets in the form of *Meet the Component: Breadboard*.

EDC: Light Show

This challenge uses the LbyM BasicBoard connected to a computer and controlled with the Web App. Participants are asked to create a light show set to music as an art installation. They each create their own light show but work with their small group for ideas and troubleshooting help.

EDC: Measuring Light

Participants are challenged to measure the brightness of light in the room and display the results on their computer. They must first become familiar with the light sensor by observing it and reviewing the *Meet the Component: Light Sensor* datasheet. Then they wire the sensor onto their BasicBoard and experiment to see how the LbyM platform responds to varying levels of light. Their setup must include a sensor correctly connected to the Arduino and breadboard. In addition, the Web App *Intro to Sensors* program successfully reads data from the sensor and the brightness readings change when the light shining on the sensor changes. They are constrained to using only the voltage from the Arduino; no other voltage sources can be used.

EDC: Night Light

Participants tackle the design and development of a night light that will turn on and get brighter as the room gets darker. To successfully complete this challenge the 4 LEDs are off when the room is brightly lit, all 4 LEDs are on when the room is completely dark, as the room gets darker, more LEDs light up, and as the room gets brighter, the LEDs turn off. Participants modify the BasicBoard to include 4 LEDS and the light sensor. They use the *Night Light Setup* Web App program to determine four levels of light appropriate for turning the LEDs on or off. Finally, they modify the *Night Light* program to control the LEDs based on the light level as determined by the light sensor. The tips for success include scaffolding in the form of a table to record the light level in Lux for the darkest room through the brightest room and indicate the number of LEDs that should be on at each level.

EDC: Winter Coat

This activity challenges participants to design a coat that will keep them warm and dry in the snow. Their resulting coat must feel soft and cozy on the inside and be flexible and waterproof. In addition, the temperature inside the coat must be maintained for 1000 seconds and it can't change by more than 4°C when a bag of ice is placed on the coat.

The designs are constrained to use only 3 of the provided materials and each material may only be used in no more than 2 layers.

To complete the challenge, participants must wire the temperature sensor into their BasicBoard, place the sensor inside the coat, and use the *Winter Coat* program (in Web App) to determine the temperature inside their coat.

Participants simultaneously test their coats using a testing protocol shared with all designers as they designed their coats. Finally, they save their data files and upload the saved csv files to the Collaborative Workspace.

EDC: Capturing Motion (Position and Velocity)

These two challenges ask participants to use the LbyM system to capture the motion of a cutout silhouette to create position vs. time graphs or velocity vs. time graphs. The goal is to create graphs that match provided graphs, thereby understanding the motion that the graph represents. To begin capturing the motion of the silhouette, they must wire an ultrasonic sensor onto the BasicBoard, set up a course with a measuring tape, and learn to use new programs, ***Position*** and ***Velocity***, in the Web App.

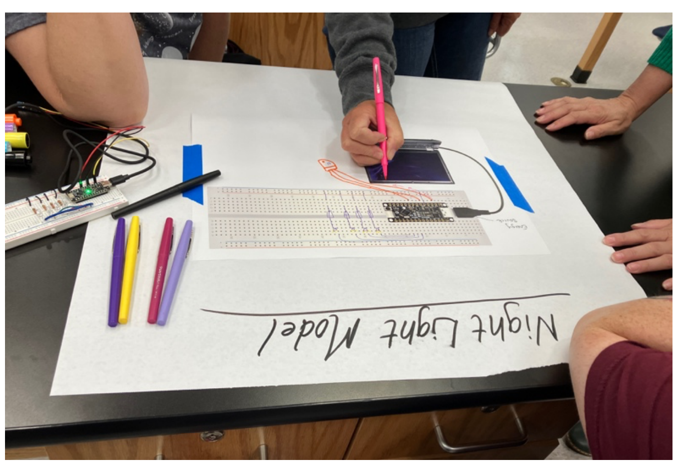
Modeling Challenges

Systems modeling is a key practice of scientists; they use it to describe the components of a system, illuminate interactions between those components, and define the boundary of the system. In addition, a systems model will typically show inputs to the system and any outputs produced.

Modeling activities can be used as a formative assessment by the teacher and by the student to identify their own learning gaps. In the context of professional learning, the participants can identify gaps in their understanding of the system being modelled and the facilitator can get a feel for what the participants are struggling with without embarrassing anyone.

The participants created explanatory models of the systems they built in the EDC activities. The instructions were brief including just a prompt and a “Gotta have it” list. Typically, they used chart paper and markers; these would commonly be found in any classroom. Sometimes they incorporated an image of the BasicBoard and added in the wiring and other components. Once the models were complete, there was a gallery walk then participants discussed as a whole group what they noticed and what they wondered.

Figure 2: Modeling a Night Light



How to Model a System

Participants are asked to make an explanatory model that describes how one of the circuits they've worked with (Interactive Card, Manufactured Connectivity tester, Participant Engineered Connectivity tester) functions. They begin by individually reading the *How do we Investigate Systems* content notes which covers systems thinking and scientific modeling. Then work with a small group to create a model of one of the systems on chart paper. They are prompted to label components, identify inputs and outputs, and describe internal interactions.

Model a Sensor System

During this challenge, participants make an explanatory model that shows how the Basic Board and WebApp gather and display varying light data. They need to show the Arduino, wires, breadboard, and light sensor and represent electrical current, electrical signal, and light.

Model Your Night Light

Teams of participants worked to make a model that shows how the night light functions. They need to include the light sensor, LEDs, digital pin outputs that act as switches and resistors and indicate the flow of electrical current. In addition, they need to show how the LED outputs respond to varying light intensity inputs and optionally, the code used to control the lights.

Science Challenges

The science challenges were chosen specifically to add depth to teachers' science content knowledge. In addition, these tasks allow teachers to consider where else in their existing science curriculum the LbyM platform could be implemented.

Visual Vocabulary

This activity is designed to add depth to participants understanding of circuits and to model a teaching strategy participants can use with their own students and is implemented after participants have built several circuits. To achieve this, the participants read content notes (CN) on *Circuits* using one or more of the suggestions from the *Reading Strategies* content notes.

Then they play a game in a group of 3 or 4 using eight cards with an image on one side and text on the other. The images are drawings of circuit components or full circuits or formulae. The text describes Current, Batteries, Resistors, Voltage, Formulas, Bulbs, Units, and Short Circuits. To begin, they place their cards image up on the table. Then, taking turns, they predict what the text side will be about and share their rationale and finally, they flip the card over and read the description.

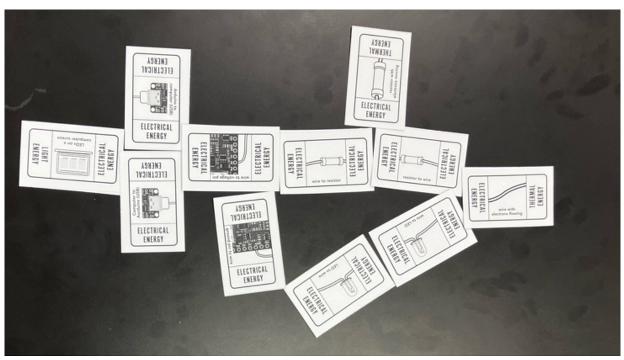
Circuit Analysis

After working together with the facilitator to analyze a circuit mathematically using Ohm's law, participants work in small groups to analyze five example circuits and answer questions like, 'How many ohms of resistance do you think the resistor provides?' and 'Will the LED light up, stay off, or risk damage?' They finish with a whole group discussion on why the LbyM platform uses 330-ohm resistors. This develops their understanding of the platform beyond what is expected in the student materials.

Energy Dominos

Participants activate their prior knowledge and add to their understanding by reading the *Energy* content notes. They are provided with a stack of energy dominos each of which represents an interaction between two components in a circuit and represents transfer or transformation of energy. They then work in teams and use energy dominos to model what is happening with matter and energy at each interaction within the circuits analyzed earlier.

Figure 3: Energy Dominoes Representing a Circuit



Mechanical Waves

Participants observe a demonstration of waves generated by sound applied to a layer of salt on a cling wrap membrane and watch a video of the interaction between a human hitting a drum and a suspended piece of fabric. As part of the whole group, they share their observations and discuss what could be causing the phenomena illustrated.

Next, participants read *Mechanical Waves* content notes and in pairs explore 4 online simulations of waves generated by speakers, tuning forks, and pulling on an object.

Light Stations

Participant groups observe light absorption, emission, and temperature change phenomena at three stations. At *Light Trails*, they observe the fluorescence that occurs as a result of using an ultraviolet pen light on a square of UV reactive pigment. At *Warming Rocks*, they examine three diagrams and work through a thought experiment relating light absorption and temperature change. At *Lizard Lamps*, they observe a fake lizard's temperature change as it absorbs infrared light from an IR bulb.

Participants read *Light Resource Review* content notes.

Group discussions about connections between the reading and phenomena observed at the stations and to the EDC activities from prior work.

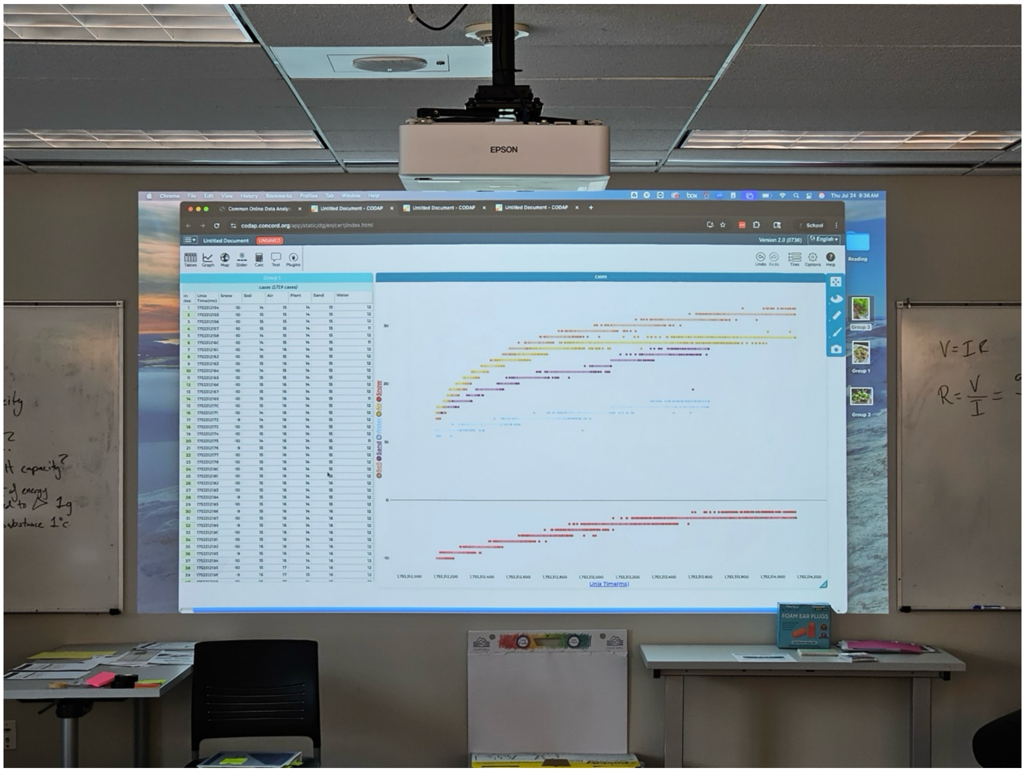
EDC: Measuring Temperature Changes

In this culminating activity, participant groups of 3 or 4 wire two LbyM platforms to control 6 temperature sensors and one light sensor, then set up an experiment to measure temperature change in 6 substances (soil, sand, water, air, plants, and shaved ice as "snow") when exposed to a lamp. While the experiment runs, participants predict what will happen to the light rays (transmission, absorption, or reflection) as they reach the matter in each cup and how those interactions will affect the temperature of each sample. After collecting and downloading the data from the experiment using the LbyM system, they name the columns and upload the data to the Collaborative Workspace. Finally, participants use solar flux maps to make sense of global surface temperature patterns, connecting their temperature experiment results to concepts of albedo and Earth's surface temperatures.

Data Analysis via CODAP

After *EDC: Measuring Temperature Changes*, the whole group participated in a discussion of the data while the facilitator demonstrated how to analyze data using the *Common Online Data Analysis Platform (CODAP, www.concord.org)* website.

Figure 4: Experimental Data using CODAP



One group's data from the experiment had been previously uploaded. The facilitator showed how to drag and drop columns to the appropriate axes and then asked participants to share what they noticed as the data for each substance (soil, sand, water, air, plants, and shaved ice as "snow") was added to the graph.

Other Challenges

BasicBoard Introduction

Participants read the Arduino datasheet. They then observe their BasicBoard comparing it to the breadboard and Arduino datasheets. Finally, they learn to connect their BasicBoard to the computer and identify whether it is connected correctly.

Introduction to coding

Participants experiment with Web App commands to control digital pins on the Arduino which are connected to LEDs. While trying the commands suggested, participants are expected to recognize that case and spacing matter in coding. In addition, they should realize which digital pin turns on which LED.

Through the Teacher Lens

In addition to these challenges, there were several other activities designed to help participants build technological pedagogical content knowledge (TPACK) around the LbyM platform.

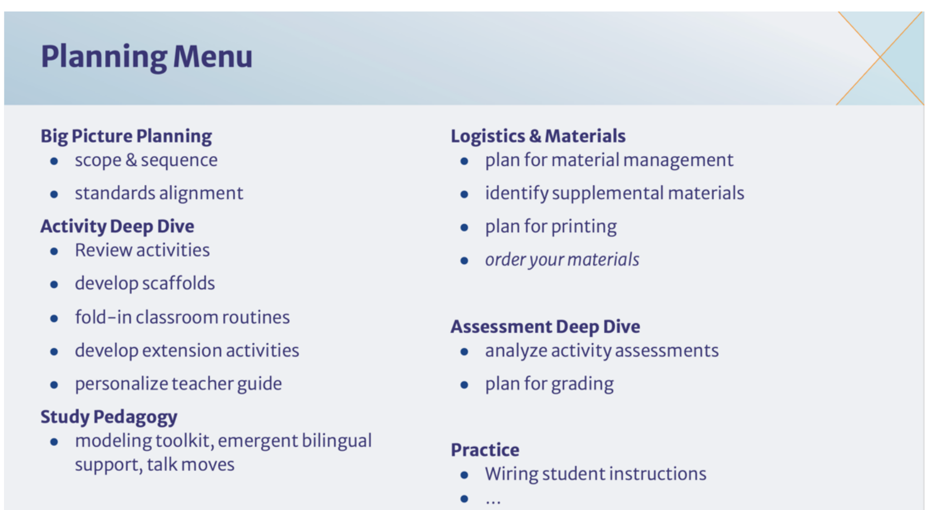
Review Student Materials

Throughout the week, participants reviewed the student materials (Guide and Worksheet) and familiarized themselves with the teacher guide for each student activity; this review always occurred after the participants had experienced an adult version of the activity. This sequence was intentional - experiencing the technological challenges firsthand allowed teachers to anticipate student difficulties and develop targeted support strategies. They were encouraged to take notes from their own experience to inform their implementation decisions.

Planning Time

Later in the week, participants were asked to work individually or in small groups to plan their implementation using a comprehensive planning menu (Figure 5) that addressed the complex realities of classroom implementation, then shared their work with colleagues on the final day.

Figure 5: Menu of Planning Activities



Implementation Order

Each Institute had the same basic goal: to prepare teachers to incorporate the STEMACES activities into their 8th grade science classes. As shown in Figure 6, the plan was to spend the first two days doing adult versions of the six STEMACES activities (with less scaffolding and compressed timelines), adding depth to participants' science content knowledge on day three, and providing time for teacher implementation planning on day four and participant sharing on day five.

Figure 6: Summer Institute Plan

STEMACES

Summer Institute, July 7 - July 11, 2025

	Day 1 - Monday 7	Day 2 - Tuesday 8	Day 3 - Wednesday 9	Day 4 - Thursday 10	Day 5 - Friday 11
8:30 - 9:00	• Breakfast	• Breakfast	• Breakfast	• Breakfast	• Breakfast
9:00 - 10:30	• Meet & Greet	• Review & Reflect	• Engineering to Science	• Design Principals & Planning Menu	• Teacher Presentations
10:30 - 10:45	**Break**	**Break**	**Break**	**Break**	**Break**
10:45 - 12:00	• Activity 1: Circuit Systems	• EDC: Night Light	• Science of Circuits	• EDC: Teacher Time: Plan for Classroom Implementation	• Closing and Next Steps
12:00 - 1:00	**Lunch**	**Lunch**	**Lunch**	**Lunch**	**Lunch**
1:00 - 2:30	• Activity 2: Light Show	• EDC: Winter Coat	• EDC: Sound Waves & Energy	• EDC: Teacher Time: Plan for Classroom Implementation	**• (Optional) Trip to the Caverns of Sonora in Sonora**
2:30 - 2:45	**Break**	**Break**	**Break**	**Break**	
2:45 - 4:15	• Activity 3: Intro to Sensors	• EDC: Capturing Motion	• Light Waves & Energy	• EDC: Teacher Time: Plan for Classroom Implementation	
4:15- 5:00	• Reflection & Closing	• Reflection & Closing	• Reflection & Closing	• Reflection & Closing	
5:00pm	**End of Day**				

Team Dinner (optional)

WIFI Info:
UN: guest.angelo.edu
PW: (not needed)

Formal Presentations
Hands-on Activity
Discussion
Brainstorming
On your own
Lunch provided

While both institutes followed the same basic structure (learning about the LbyM system first, extending that into science activities and then considering how it could be used to teach middle school science) the actual implementation differed from the original plan and varied between sites (see Table 1). In Texas the six STEMACES activities fit into the first two days as planned, but in California they were distributed across the first three days, creating more space for content-deepening activities like Visual Vocabulary and Circuit Analysis earlier in the week. Both sites integrated the modeling challenges immediately after participants completed each corresponding activity rather than clustering them separately. The science content depth work was woven throughout the week in both locations, with activities like Energy Dominos, Mechanical Waves, and Light Stations interspersed with the engineering design challenges. As planned, participants reviewed student materials and teacher guides after experiencing the corresponding activities which allowed them to record their reflections immediately. They could then use those reflections during the teacher planning time on Day 4 and participant sharing on Day 5.

Table 1: Implemented Activity Schedule

	Texas	**California**
Day 1 AM	EDC: Making an Interactive Card EDC: Making a Connectivity Tester Modeling Systems	EDC: Making an Interactive Card EDC: Making a Connectivity Tester Modeling Systems
Day 1 PM	BasicBoard Introduction Introduction to Coding EDC: Designing a Light Show Perusal of Student Materials & Teacher Guide for Activities 1 & 2 EDC: Measuring Light Model a sensor system	BasicBoard Introduction Introduction to Coding EDC: Designing a Light Show Visual Vocabulary Circuit Analysis Perusal of Student Materials & Teacher Guide for Activities 1 & 2
Day 2 AM	EDC: Night Light Perusal of Student Materials & Teacher Guide for student EDC: Night Light activity Modeling a Night Light	EDC: Measuring Light Model a sensor system

	Texas	California
Day 2 PM	EDC: Winter Coat Model a System EDC: Capturing Motion Model the Ultrasonic Sensor Perusal of Student Materials & Teacher Guide for student EDC: Capturing Motion Activity	Perusal of Student Materials & Teacher Guide for Activity 3 EDC: Night Light Modeling a Night Light Perusal of Student Materials & Teacher Guide for student EDC: Night Light activity Discussion of NGSS practices & cross-cutting concepts
Day 3 AM	Visual Vocabulary Circuit Analysis Energy Dominos	EDC: Capturing Motion Model the Ultrasonic Sensor Mechanical Waves Revise Model of Ultrasonic Sensor Perusal of Student Materials & Teacher Guide for student EDC: Capturing Motion Activity
Day 3 PM	Mechanical Waves Revise Model of Ultrasonic Sensor Light Stations EDC: Measuring Temperature Changes	EDC: Winter Coat Model a System Perusal of Student Materials & Teacher Guide for student EDC: Winter Coat EDC: Measuring Temperature Changes
Day 4 AM	Data Analysis via CODAP Solar Flux and Global Surface Temperature Teacher Planning Time	Data Analysis via CODAP Teacher Planning Time
Day 4 PM	Teacher Planning Time	Teacher Planning Time
Day 5	Teacher Presentations	Teacher Presentations

Findings

Computational Thinking

Participants developed computational thinking skills through authentic scientific practices and gained pedagogical strategies for developing these skills in middle school science.

Data Practices

The LbyM system is designed to facilitate collecting data, visualizing data, and analyzing data. During several PL activities, participants had opportunities to explore those features and begin to recognize the challenges scientists face when collecting data with sensors.

During their first experience using the system to collect data with the light sensor (*Measuring Light EDC*), participants saw that the data produced was “messy” in that it wasn’t a consistent value even when the light input didn’t appear to change.

The *Winter Coat EDC* provided an opportunity for them to collect data using the temperature sensor. Here participants began to recognize the limitations of the system as one computer kept going to sleep and cutting off data collection.

The *Capturing Motion EDC* allowed participants to dig deeply into how motion is represented in time vs position and time vs velocity graphs. In trying to reproduce provided visualizations, they were challenged to connect their mental models of motion with what data was being collected and displayed in the graph.

Finally, participants collected data relevant to a science experiment during the *Measuring Temperature Changes EDC* activity. There was rich discussion about how they could control the variables (such as sensor depth in the substance) in order to produce comparable data. While involved in the *Data Analysis via CODAP* activity, participants experienced the sensemaking that happens during a post experiment analysis of collected data. One participant expressed that she was “excited about how many more questions I had [about the results] because we did this; that interest gets you to think about things.”

Modeling and Simulation Practices

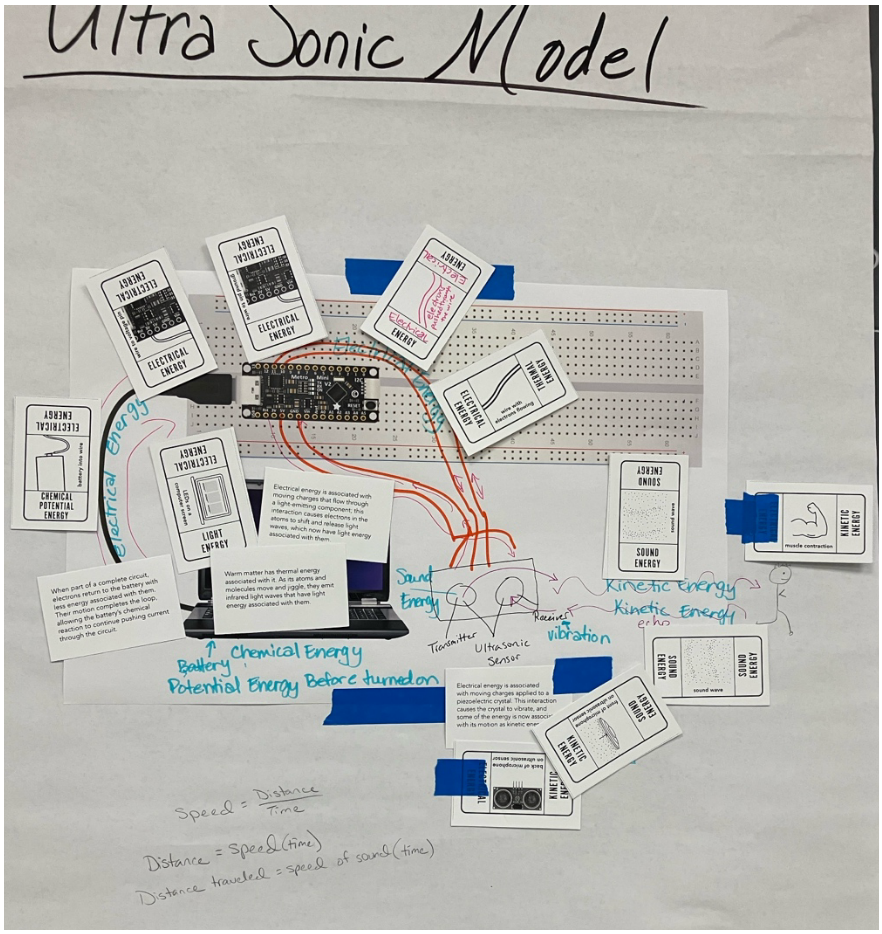
While the Weintrop taxonomy focuses on using, assessing, designing and constructing computational models at the high school level, middle school students benefit from developing foundational modeling practices through creating and revising explanatory models of systems they have built and tested.

The modeling challenges develop modeling practices by first asking for a model without specifying many requirements (just a basic “Gotta have it” list). Each successive modeling challenge adds more stringent requirements for what must be included and finally participants co-develop their own list of what should be represented in the model.

Twice, participants experienced how models change over time when new information is uncovered. First, by analyzing the provided visual models of circuits, then adding mathematical relationships during the *Circuit Analysis* activity, and finally, adding another layer representing energy during the Energy Dominos activity. The second time was when they modified their initial ultrasonic sensor models based on the information gathered during the *Mechanical*

Waves activity. Each revision makes the model more representative of the system. This progression gave participants direct experience with scaffolded modeling that they could adapt for their own students.

Figure 7: Final Ultrasonic Sensor Model



We observed one participant draw and use a model of the Earth's position and axis tilt at each of the solstices and equinoxes in order to make sense of the solar flux maps. This provided evidence that she clearly understands how models help us think through and expand our understanding of science concepts and how we can revise our mental models as new information becomes available.

Participants interacted with four simulations during the *Mechanical Waves* science challenge but there wasn't much discussion around the benefits and limitations of simulations as models of systems. For example, no one seemed to notice that the sensor in the simulated speaker system always produced the same waves for the same settings.

Computational Problem-Solving Practices

Within the scope of a middle school science class, it isn't possible to address all of the computational problem-solving practices. The STEMACES program emphasizes troubleshooting and debugging and introduces novice computer programming skills. There are also opportunities to assess different approaches/solutions to a problem, develop modular computational solutions, and create computational abstractions.

The facilitator modeled the development of a LbyM troubleshooting list by providing a starter list with just a few ideas (try things, ask how others are doing it, send a spy). As part of the debriefing of each EDC, participants reflected on challenges they faced and how they overcame those challenges and added the strategies identified to the troubleshooting list.

Participants immediately began applying these troubleshooting skills in the initial engineering design challenge, *Making an Interactive Card*. Several participants had trouble creating a complete, non-shorting circuit with the provided materials. After *EDC: Light Show*, they added check your USB connections, click connect (check top right), and could be a bad bulb to the troubleshooting list. They continued adding to the list after each EDC as they discovered other things that might go wrong with the setup. This systematic approach to building a collaborative troubleshooting resource gave participants both technical problem-solving experience and a pedagogical strategy they could implement with their own students.

Initial exposure to programming in the LbyM system happened during the *Introduction to Coding* challenge. While exploring carefully selected commands, participants identified that commands in the Web App are case- and spacing- sensitive. In this short time, they were able to identify what each command did by observing the resulting light output on the BasicBoard or reading the error message in the terminal window.

Systems Thinking Practices

All of the STEMACES PL activities (and student activities) are designed to develop systems thinking practices as used in real-world science. They provide opportunities to investigate complex systems as a whole, understand the relationships within a system, think in levels, define systems, manage complexity, and communicate information about a system.

When participants examined the complete light measurement system (BasicBoard + sensor + computer + Web App), they had to understand how all components worked together rather than focusing on individual parts.

The circuit modeling activities required participants to trace complex relationships between components, tracing the complete information flow from sensor input through Arduino processing to the Web App and back to control system output. This tracing exercise exemplified "understanding relationships within a system" as participants had to map both the physical connections and the information flow between components. When revising the circuit models during the Energy Dominos activity, participants again had to consider the physical connections and how those connections led to energy transfer or transformation.

Troubleshooting the various systems naturally revealed component interdependencies (USB connection affects communication between hardware and software). This process helped participants understand that changing any single component – sensor, Arduino programming, or Web App parameters – would affect the behavior of the entire system.

Participants communicated information about systems each time they created a visual representation (model). The "Gotta have it" modeling requirements helped participants define essential system components and boundaries. In addition, the troubleshooting list development required participants to articulate system problems and solutions clearly.

Technological Pedagogical Content Knowledge (TPACK)

Participants developed sophisticated integration of content, pedagogical, and technological knowledge, transforming from hesitant technology users to confident practitioners ready to implement STEMACES activities in the classroom.

Content Knowledge (CK)

Circuits: Participants developed content knowledge of circuits by first exploring several circuits during the engineering design challenges and then learning to explain circuits using accurate scientific vocabulary during the *Visual Vocabulary* and *Circuit Analysis* activities.

Engineering: The *EDC: Connectivity Tester* activity introduced datasheets and how they are used by engineers during the design process to understand the features and limitations of various components. Each participant considered the process they used to design the tester then compared that process with the group. They noticed that while each completed several of the same steps (such as imagining and planning possible solutions) they did not necessarily do them in the same order or the same way. This understanding that there is not just one ENGINEERING DESIGN PROCESS (similar to the understanding that there is not one scientific method) is essential to successful implementation of the STEMACES activities. While completing the *Winter Coat EDC*, participants were exposed to the idea that engineers test competing designs by using a testing protocol based on the criteria and constraints.

Energy: The *Energy Dominos* modeling task helped participants add scientific language to their explanations of energy transfer and transformation that occurs within circuits, especially the types of energy.

Waves: Both the *Mechanical Waves* and *Light Stations* activities started with interesting phenomena that might pique the interest of participants and encourage them to dig deeply into the provided readings and make connections between the information from the readings and the phenomena they observed. Clearly this strategy worked as we observed participants reacting with enthusiasm and discussing their many ideas about what might be happening in each case. Then they tried to satisfy their scientific curiosity by diving into the reading with alacrity and focus.

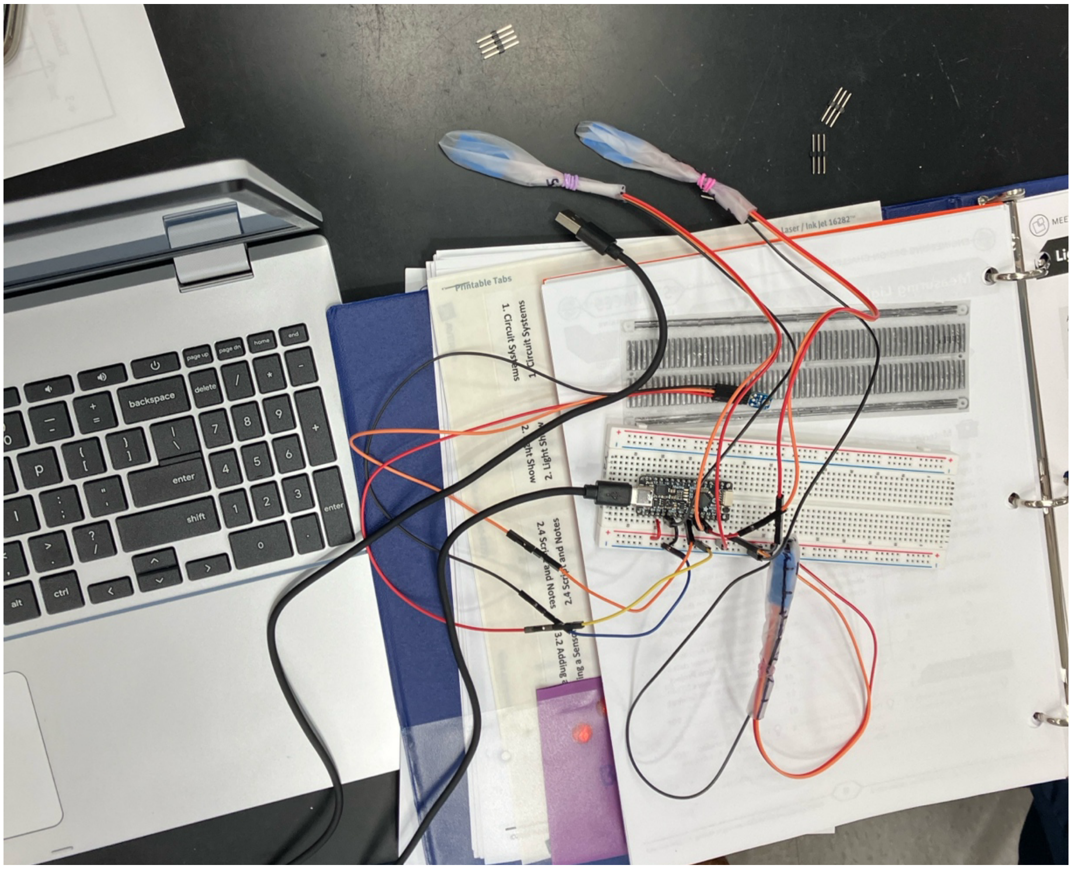
Pedagogical Knowledge (PK)

Although development of pedagogical knowledge was not a main focus of the Summer Institute as the participants were all experienced teachers, participants could have picked up some implicit pointers just by observing the facilitator during each activity. The *Visual Vocabulary* activity specifically incorporated a strategy to get students discussing the science content. In each activity where reading content notes was expected, the facilitator reminded the participants to review the *Reading Strategies* and choose one or two to try during that reading; teachers could use this same student-centered approach with their students. During the teacher planning time on Day 4, several teachers considered the *Talk Activities Flowchart* which identifies several strategies to get students talking about science. One participant focused on this in conjunction with *The Modeling Toolkit* (Windschitl & Thompson, 2013) article to consider the best ways to use STEM and STEMACES activities to encourage her EL students to talk, model, and read while practicing their content specific English language skills.

Technological Knowledge (TK)

By meeting each engineering design challenge, participants developed proficiency and confidence in their electronics (aka wiring circuits) and coding abilities. One participant clearly exemplified this as she went from feeling so frustrated and overwhelmed that she had to leave the room when wiring her Night Light on the morning of the second day to being the quickest to complete the setup for the experiment on the afternoon of day 3 and helping others with their wiring. This transformation from paralysis to proficiency exemplified the kind of technological fluency that enables teachers to focus on student learning rather than troubleshooting equipment. Although she was the most dramatic example, she was not the only one; all of the participants showed that they needed little help with the LbyM platform by the afternoon of the third day. They read the *Measuring Temperature* challenge, asked a few questions to clarify the task, and then proceeded to setup for the experiment proficiently and with confidence.

Figure 8: Setup for Measuring Temperature Experiment



The *Winter Coat EDC* provided participants with the opportunity to familiarize themselves with the plotting capabilities of the LbyM system.

When asked “What are some things you’ve learned that you didn’t know or know how to do earlier?” at the end of Day 1, participants listed both foundational technical skills and more sophisticated system understanding. Basic technical knowledge included learning “how to attach the leash” and “how to use copper tape”, while programming skills emerged as participants described learning to “use waits/repeats, turn on/off lights.” More advanced technological understanding was evident in responses like learning “how to interpret the symbols on the Arduino” and discovering that using the wrong voltage pin “won’t damage the sensor.”

Pedagogical Content Knowledge (PCK)

While pedagogical content knowledge for science and engineering is complex and multi-faceted, far beyond what can be developed in one week, the STEMACES PL effectively demonstrated several of those facets and related strategies through authentic modeling.

There is no one “scientific method” although investigations typically begin with the observation of a phenomenon. Similarly, the *Mechanical Waves* and *Light Stations* activities began with participants observing phenomena such as a suspended piece of fabric moving after someone hits a big drum (a demonstration via video) or the light trails generated as they draw on a square of unidentified material (directly interacting with materials in *Light Trails*).

The “Explore then Explain” approach is embedded in the 5E instructional model (Bybee et al. 2006) commonly used in science classrooms across the country and is incorporated throughout the summer institute. Participants always have an opportunity to interact with the material and construct their own understanding (explore) before they are exposed to current scientific thinking about the content (input from experts).

One strategy for examining matter and energy in a system is to look at each interaction and evaluate the type of energy involved and whether it is transferred or transformed. The *Energy Dominos* activity helped participants see the value of this strategy. They also recognized that there are limitations to this representation of interactions occurring within a system because it represents only one input and one output. They discussed options for classroom use including using multiple dominoes to represent one component to component interaction or possibly having students use other shapes (like hexagonal thinking templates) and develop their own representations.

Through these experiences, participants developed the kind of content-specific pedagogical reasoning that distinguishes effective science teaching from generic instruction – they didn’t just learn strategies, but understood rationale behind when, how, and why to use them.

Technological Pedagogical Knowledge (TPK)

The technological pedagogical knowledge necessary for incorporating the LbyM platform into the middle school classroom involves understanding how to manage the materials, how students will interact with the materials, and best practices for helping students learn to use the platform as a tool in their arsenal. Teachers developed this knowledge through their own use of the platform during design challenges, by reviewing the teacher guide and student materials, and by discussing potential facilitation strategies with the facilitator and each other.

There were many discussions of how to develop student agency during troubleshooting and how to manage the multiple materials necessary to complete the student activities. These discussions revealed teachers' growing sophistication in thinking beyond individual tool use to orchestrating technology-rich learning environments that promote student agency and scientific reasoning.

Several participants noted that the practice of working together supported their learning, with one saying, “seeing this thing [BasicBoard] is overwhelming, everybody was so helpful and working together made it relaxing and easy to handle.” This experience developed teachers' understanding of how collaborative structures can reduce technology anxiety and cognitive load, essential pedagogical knowledge for implementing the LbyM system in middle school classrooms.

Technological Content Knowledge (TCK)

The LbyM platform can be used to gather data using sensors. Participants got firsthand experience of how this feature supports engineers while designing their night lights and winter coats; the platform allowed them to collect the necessary light and temperature information without adding a heavy cognitive load. Similarly, they collected data as scientists do while experimenting with capturing the motion of the silhouette with the ultrasonic sensor and measuring temperature changes in various substrates. By the end of the week, participants could see the platform as another tool like the meter sticks and thermometers they are used to.

Bringing it all together (TPACK)

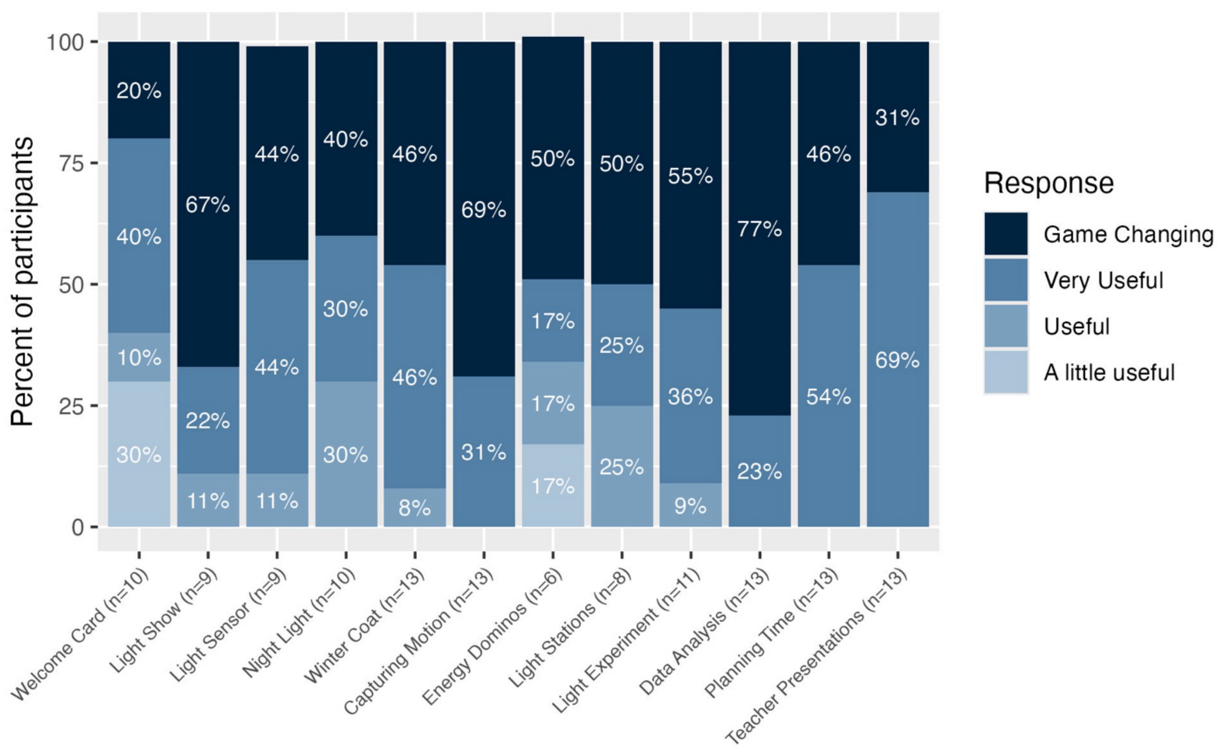
The LbyM platform can be used to collect data from science experiments in middle school classrooms. That data can then be analyzed and the conclusions drawn during that analysis can inform students' scientific understanding of the world. The culminating *EDC: Measuring Temperature Changes* and *Data Analysis via CODAP* activities revealed participants readiness to extend beyond the foundational STEMACES activities, demonstrating the integrated TPACK competence needed to innovate with the LbyM platform in their classrooms.

During the planning time, participants delved deeply into the facets of TPACK while deciding where to insert STEMACES activities into their courses. The complexity of their thinking was evident as they juggled multiple considerations: aligning activities with content and practice standards (NGSS, TEKS), fitting them into their scope & sequence (district supplied or class level), and addressing practical implementation challenges. Some delved deeper, connecting activities to released 8th grade assessment questions while others considered how to seamlessly integrate the STEMACES activities into established classroom processes and routines, like science notebooks, and at least one teacher used this time to practice wiring all of the activities from scratch without the time crunch of the EDCs.

Participant Ratings of Activity Usefulness

In the survey, participants rated the usefulness of individual activities on a five-point scale from "Not useful at all" to "Game Changing" (Figure 9). Across all activities, participants provided predominantly positive ratings, with most activities achieving at least 80% combined "Game Changing" and "Very Useful" responses and no one selected "Not useful at all". Sample sizes varied from 9 to 13 participants depending on attendance. The general pattern suggests strong participant satisfaction with the activity sequence, though these small sample sizes preclude drawing firm conclusions about specific activity effectiveness. Additionally, survey respondents included both participants new to STEMACES and those with previous program experience, which may have influenced their perceptions of usefulness. Future professional development could consider differentiating expectations and potentially survey questions for new versus returning participants to better tailor the experience to each group's needs.

Figure 9: Usefulness of Activities



Superb facilitation creates an environment in which participants feel empowered to take risks and push beyond their comfort zone.

Throughout the entire Summer Institute, the facilitator modeled a “guide on the side” vs “sage on the stage” science teaching approach (King 1993),which emphasizes student-centered learning where teachers facilitate discovery rather than simply transmitting information. The "guide on the side" approach aligns with constructivist learning theory, which holds that students must actively construct understanding rather than simply receive and store information packages from teachers. This active learning approach emphasizes learner involvement, learning by doing, and connecting ideas, which helps prevent the development of "inert" knowledge that is simply stored rather than used or tested in different ways. This approach helped participants have agency over their own learning versus acting as an empty vessel to be filled by “experts”.

Participants' survey responses confirmed the impact of this facilitation approach. When asked about features that contributed to their success and enjoyment, they consistently emphasized the facilitator's ability to create a safe environment for productive struggle. One participant captured this: “The positive environment with the encouragement and collaboration gave me a sense of safety to face my fears and take risks.” Another noted appreciation for “how [the Facilitator] facilitated and let us struggle with some things while ensuring supports are available.” The scaffolded support was particularly valuable for participants entering with varying experience levels, with one noting, “From the perspective of someone who arrived to the course with zero knowledge I think the scaffolding used during the different sessions to bring the participants up to speed was absolutely efficient.”

Table 2 lists some of the key facilitation moves observed during the Institutes that created this supportive yet challenging learning environment. Participants responded naturally to these facilitation moves by participating fully and persevering through every challenge with 92% rating their overall satisfaction as “Excellent” and the remaining 8% as “Very Good.”

Table 2: Key Facilitation Moves

Facilitation Move	Description	Example
Establishing Climate & Expectations	• Welcoming, knows everyone’s name, treats each person with respect, accommodates diverse needs. • Co-creates a Norms & Troubleshooting document. Revisits regularly and adds by paraphrasing participant wording. • Value what participants bring to the experience.	• Adds “mind your caps” and “click connect” to the troubleshooting table. • “If you aren’t uncomfortable, you might not be pushing yourself.”
Modeling activity facilitation	• Models multimodal instructions when assigning a task to “students”. • Makes suggestions but leaves the choice up to the participant. • Provides individual extension challenges to those who finish early.	• As he introduces the activities and materials, he holds up whatever he is talking about and points to area under discussion. • “You might want to do one LED first, check it, then add another.” • “Now that you’ve got it working, can you determine the bounds of the light sensor?”

Facilitation Move	Description	Example
Not the font of all knowledge	• Asks questions that help participants find their own answers. • Asks questions that help participants articulate their understanding. • Doesn't provide answers.	• "Does the datasheet say something about that?" • "Tell me what you are thinking." • Sometimes nods or says "That makes sense to me" when a participant provides an answer.
Notice and Wonder	• Prompts participants to articulate their observations (What do you notice? What do you wonder?) • Uses the same prompt when presenting something on the screen (sometimes uses cursor to rest on something he wants them to notice). • Asks in a way that helps them focus on one thing at a time.	• Prompt for each gallery walk of created models • (Coding Challenge) What do you notice about syntax? What do you notice or wonder about electrical current and/or circuits? • (Solar Flux Maps) What are some things coming up? What is this reminding us we know about Earth and Sun?
Sunshine's & Blues	• Provides daily opportunities for participants to share their positive and negative views of the day. • The next day revisits each shared idea. Some were consolidated and reworded. Honors each response and turns any that can be into learning moments, community norms, or sometimes a joke.	• "Your input matters. Put <> on blue Post-it, yellow something you really loved. If it's none, just put none." • Blue displayed "Anxiety with timed activities"; pointed out that the timer can be considered a suggestion and that on EDCs the constraint is often time.

The effectiveness of these facilitation strategies is evident not only in participants' satisfaction ratings but in their confidence levels and enthusiasm for implementation. The combination of modeling best practices, encouraging productive struggle, and creating psychological safety resulted in 70-80% of participants reporting high confidence (Extremely or Very confident) for implementing most activities.

Conclusion

The ultimate measure of the Summer Institutes' success will be participants' effective implementation of STEMACES activities in their classrooms. However, our observations documented substantial development across computational thinking practices and TPACK domains, coupled with high levels of confidence and enthusiasm. As one participant expressed,

> *"This was hands-down the BEST professional development opportunity I have ever attended. I am so excited about giving our students these opportunities to learn."*

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Appendix A - Activity Time Details

This table details the time spent on each activity during the Texas Institute. With minor changes and some reordering, the time spent was the same for the California experience.

Activity	Texas
EDC: Making an Interactive Card **Design and construct a memorable, interactive card to introduce yourself and your environment.**	Day 1 9:45-10:37 • Participant teams work together (30 minutes) • Sharing (5 minutes) • Debrief by comparing to Engineering Design Process model (10 minutes) • Debrief by reflection on norms (7 minutes)
EDC: Connectivity Tester **Design and construct a functioning connectivity tester.**	Day 1 10:52 – 11:24 • Practice with manufactured connectivity tester (6 min) • Participants work on building testers in consultation with team members (26 minutes)
Modeling systems **Make an explanatory model on chart paper that describes how one of your circuits functions.**	Day 1 11:25-11:50 • Participants read “How do we investigate systems?” content notes (3 minutes) • Participant teams develop models (15 minutes) • Gallery Walk and Debrief (7 minutes)
BasicBoard Introduction	Day 1 11:50-12:05 and 1:17-1:27 • Participants read Arduino datasheet while comparing to their BasicBoard (10 minutes) • Watch a video example of a lightshow (5 minutes) • Connect BasicBoard to computer (10 minutes)
Introduction to Coding	Day 1 1:28-1:58 • Participants experiment with commands to control digital pins and changing code in “lightshow” script (20 min) • Debrief by discussing what they tried, noticed (10 min)

Activity	Texas
EDC: Designing a Light Show **Create a light show set to music as an art installation.**	Day 1 1:58-3:23 • Participants (working with their group) create individual light shows to meet criteria within constraints. • Participants upload code to collaborative workspace.
Perusal of Student Material & Teacher Guide for Activities 1 & 2	Day 1 3:23 – 3:59 • Participants review student materials & teacher guide. (min) • Debrief by discussing what they noticed and wondered.
EDC: Measuring Light **Measure the brightness of light in the room and display the results on your computer.**	Day 1 4:00 – 4:25 • Participants wire sensor onto their BasicBoard (working with group). (23 min) • Participants experiment to see how LbyM platform responds to varying levels of light. • Participants review student materials for Activity 3 and teacher guide
Model a sensor system **Make an explanatory model that shows how the Basic Board and WebApp gather and display varying light data**	Day 1 4:25 – 4:45 • Participants modeled the sensor system. (20 min) • Gallery Walk (2 min)
Closing	Day 1 4:45-5:00 • What are some things you've learned that you didn't know or know how to do earlier today? • What were some things you did to overcome challenge? • Sunshine's & Blues
Opening	Day 2 (9:00-9:25) • Sunshine's & Blues • Revisit Norms

Activity	Texas
EDC: Night Light **Design a night light that will turn on AND get brighter as the room gets darker**	Day 2 (9:25 – 11:07) • Participants wire BasicBoard setup to include the light sensor and 4 LEDs (working with group). (23 min) • Participants use *Night Light Setup* program (in webapp) to determine light levels appropriate for night light. • Participants modify *Night Light* program to turn on/off LEDs based on light level as determined by the sensor.
Perusal of Student Materials & Teacher Guide for student *EDC: Night Light* Activity	Day 2 (included in above) • Participants review student materials & teacher guide. • Debrief by discussing what they noticed and wondered.
Modeling Night Light **Make an explanatory model that shows how the night light functions.**	Day 2 (11:07 – 11:37) • Participant teams develop models (23 minutes) • Gallery Walk and Debrief (7 minutes)
EDC: Winter Coat **Design a coat that will keep you warm and dry in the snow.**	Day 2 (11:37 – 12:00 and 1:00 – 2:02) • Participants read the challenge and ask clarifying questions. • Participants (working with group) wire the temperature sensor into their BasicBoard. (min) • Participants design a "coat" using provided materials. () • Participants use *Winter Coat* program (in webapp) to determine the temperature inside their coat. • Participants simultaneously test their coats using a testing protocol. • Participants save their data files and upload to the Collaborative Workspace.
Model a System **Make an explanatory model that describes how your winter coat worked or didn't work**	Day 2 (2:02 – 2:19) • Participants co-created a "Gotta have it" list identifying what must be included in the model. (3 min) • Participant teams develop models (14 minutes) • Gallery Walk (2 min)

Activity	Texas
EDC: Capturing Motion **Use the Ultrasonic Sensor and Arduino to generate Position Graphs.** **Use the Ultrasonic Sensor and Arduino to generate Velocity Graphs.**	Day 2 (2:20 – 4:00) • Participants (working with group) wire the ultrasonic sensor into their BasicBoard. (30 min) • Participants use *Position* program to capture the motion of a silhouette and create position vs. time graphs. (30 min) • Participants use *Velocity* program to capture the motion of a silhouette and create position vs. time graphs. (20 min)
Model the Ultrasonic Sensor **Make a model that explains how your ultrasonic sensor system functions to provide you with position data.**	Day 2 (4:06 – 4:20) • Participant teams develop models (14 minutes)
Perusal of Student Materials & Teacher Guide for student EDC: Capturing Motion Activity	Day 2 (4:20-4:29)
Closing	Day 2 (4:29 – 4:45) • What are some things you've learned that you didn't know or know how to do earlier today? • What were some things you did to overcome challenge? • Sunshines & Blues
Opening	Day 3 (9:08 – 9:15) • Sunshines & Blues
Visual Vocabulary Warm-up	Day 3 (9:16 – 9:52) • Participants read *Circuits* and *reading strategies* content notes. • Participants play Visual Vocabulary card game. • Whole group discussion of benefits of game for participants and possible uses with students.
Circuit Analysis	Day 3 (9:52 – 10:45 • Facilitator interactively demonstrates how to analyze a circuit. (5 min) • Teams of participants analyze 5 circuits and answer a question for each. (30 - 45 min) • Whole group discussion of STEMACES rationale for using 330 ohm resistors on the BasicBoard.

Activity	Texas
Energy Dominos	Day 3 (11:05 – 11:52) • Participants read *Energy* content notes. (10 min) • Participant teams use energy dominos to model what is happening with matter and energy at each interaction within each of the circuits analyzed earlier. • Whole group discussion of benefits of modeling activity
Mechanical Waves	Day 3 (1:02 – 1:48) • Participants observe and discuss a demonstration of waves generated by sound applied to a layer of salt on a cling wrap membrane. (10 min) • Participants watch a video of the interaction between a human hitting a drum and a suspended piece of fabric. Then discuss their observations. (7 min) • Participants read *Mechanical Waves* content notes. (5 min) • Pairs of participants explore 4 online simulations of waves generated by speakers, tuning forks, and pulling on an object. (24 min)
Revise Model of ultrasonic sensor **Make a model that explains how your ultrasonic sensor system functions to provide you with position data.**	Day 3 (1:49 – 2:07) • Participant groups revise their previously created models by adding content from the videos, simulations, and/or energy dominos. (18 min)
Light Stations **Explore the stations and discuss "What is happening with matter?" and "What is happening with waves?".**	Day 3 (2:22 - 3:04) • Participant groups observe phenomena at stations: 1) Light Trails 2) Warming Rocks and 3) Lizard Lamps (22 min) • Participants read *Light Resource Review* content notes. • Group discussions about connections between the reading and phenomena observed at the stations and to the EDC activities from prior work.
EDC: Measuring Temperature Changes **Plan and implement an investigation where you measure the temperature change of six substances as a result of absorbing light waves.**	Day 3 (3:04 – 4:50) • Participant groups wire two LbyM platforms to control 6 temperature sensors and one light sensor. • Participants set up an experiment to measure temperature change in 6 substances when exposed to a lamp. • Participants collect and download data from the experiment using the LbyM system. Then, they name the columns and upload the data to the Collaborative Workspace.

Activity	Texas
Closing	Day 3 (4:50 – 5:00 • Sunshine's and Blues
Opening	Day 4 (9:13 – 9:27) • Sunshine's and Blues
Data Analysis via CODAP	Day 4 (9:27 – 9:49) • Facilitator displays a dataset collected by one participant group on the previous day and walks participants through the process of analyzing the data using CODAP. • Participants ask and answer questions while making sense of the data. • Whole group discussion of how the CODAP tool could be used in the middle school science classroom.
Solar Flux and Global Surface Temperature	Day 4 (9:49 – 10:03) • Participants use solar flux maps to make sense of global surface temperature maps.
Planning Time	Day 4(10:03 – 4:45)
Opening	Day 5 (9:05 – 9:15) • Sunshine's and Blues
Participant Presentations	Day 5 (9:15 – 10:00) • Participants share the results of their independent planning time and exchanged ideas.
Closing	Day 5 (11:00 – 12:00 • Additional materials distribution • Review of provided materials • Logistics of materials fulfillment • Thank you