

Lighting Up History

Integrating Mathematics and Computational Thinking in the Science Classroom

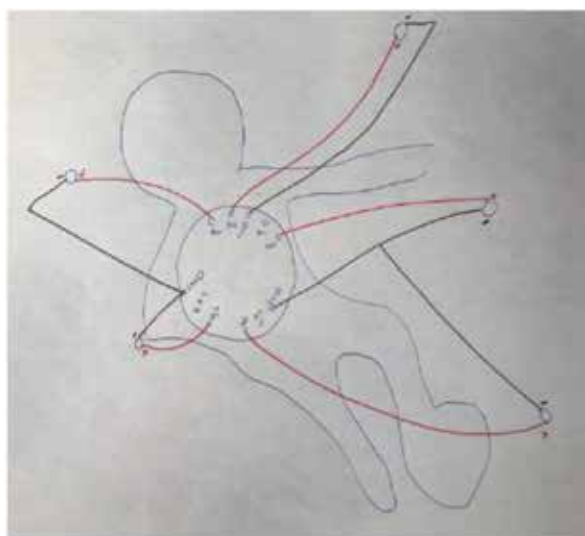
BY KRISTIN SEARLE, COLBY TOFEL-GREHL, AND BETH L. MACDONALD

Computational thinking skills are central professional practices across science disciplines. Students need to engage in these skills during their K–12 education to be prepared for STEM careers. Weintrop and colleagues (2016) identified four major areas where mathematics and computational thinking connect to scientific practice: (1) working with data, (2) modeling and simulation practices, (3) using programming and computers to

solve scientific problems, and (4) systems thinking practices. This article shares one project, a programmable paper circuit timeline that highlights the use of mathematics and computational thinking practices in the middle school science classroom while students learn science history. By programmable paper circuit, we refer to a circuit that is created using copper tape and light-emitting diode (LED) lights, but then is connected to a microcontroller so that it be-

comes programmable (see Figure 1). The copper tape is like a sticker, with adhesive on one side. However, the adhesive is not always conductive. This programmable paper circuit allows teachers to engage students in a learning activity that explores the concepts of energy conversion (from electric to light energy), energy storage, and polarity. Through the construction of this computational circuit, students learn about these concepts. In introducing the proj-

FIGURE 1: Left: circuitry diagram clearly distinguishing between positive and negative lines. Right: completed Mae Jamison timeline with the LEDs programmed to light up in sequence.



ect, teachers are able to provide direct instruction around these concepts that is anchored in the phenomena students encounter with their circuits. Free detailed and standards-based lesson plans on the science content can be found at the Chaos Learning Lab (see Online Resources for link).

The Lighting Up History Project

Project overview

Middle school science teachers often seek to engage students in learning portions of the history of science and innovation as part of their work around the *Next Generation Science Standards* (NGSS) focused on *Influence of Science, Engineering, and Technology on Society and the Natural World* (NGSS Lead States 2013). To begin the activity, ask students what they want to know about a famous scientist or engineer or an invention. Sample questions might be: “Who wrote the first computer program?” or “Who is a famous epidemiologist?” Students can conduct research to answer their questions. The teacher may curate some readings from CommonLit (see Online Resources), a free resource for classroom readings for educators, and other sources. Lighting Up History is an excellent opportunity to engage students with scientists and engineers who look like them in terms of gender, race, ethnicity, and language. For the purposes of this article, we orient our project around Mae Jemison, the first Black female astronaut.

Based on their research, students plan, create, and program a paper circuit timeline of key events in the person’s life (see Figure 1). The lights are programmed to light up in sequential order of the events, beginning with the earliest life event. Working in small groups, students experiment with the programming of their timeline and troubleshoot the circuitry and their code. Through this process, students improve on their designs. If time allows, students can share their timelines for peer feedback. Completed timelines can be displayed. See safety note at the end of this article.

Initial inquiry

This initial inquiry activity serves as both a circuitry refresher and an introduction to working with copper tape, LEDs, and batteries. After students watch a short video (“Getting Started With Copper Tape”; see Online Resources) on working with copper tape and their teacher reviews relevant safety precautions, students are given circuit templates to complete for simple, parallel, and series circuits (see Supplemental Materials). Students are asked to observe differences between the circuits, specifically how many batteries are required to illuminate the same number of LEDs in different kinds of circuits (simple and parallel circuit templates typically only require one coin cell battery, while a series circuit requires two). This allows for meaningful peer- and teacher-led discussions on energy trans-

fer and the conversion of electric energy, stored in the battery, to be converted into light energy by channeling electrons through an LED bulb. Once students ob-

CONTENT AREA

Physical Science

GRADE LEVEL

6–8

BIG IDEA/UNIT

Energy

ESSENTIAL PRE-EXISTING KNOWLEDGE

None

TIME REQUIRED

1–1.5 hours

COST

\$34/student [\$2.22 in consumable materials, many supplies are reusable year to year]

SAFETY

Caution students about sharp edges of copper tape and use of scissors. Students should wear safety goggles when cutting the copper tape and assembling the programmable paper circuit.

serve the difference between how many lights can be lit on a parallel and series circuit, the teacher can ask, “Why does the parallel circuit light up more bulbs?” We would expect students to reply with an explanation of how all the electrons in a series circuit that make it to the second bulb have gone through the first bulb. Further conversation should direct students to comparing and evaluating ideas around how the path and flow of electrons impacts resistance and other concepts.

The task

As described previously, students, working in collaborative groups of three to four, research any person of interest to them. Here, we use Mae C. Jemison as an example. After wondering about the first Black woman astronaut, students conduct research on Mae C. Jemison, who was the first Black woman

to travel into space (see Mae Jamison: Astronaut Biography in Online Resources). Next, they are asked to select three to five key moments in Jemison’s life. With these key moments in mind, students work to create a light-up timeline of key events in Jemison’s life, such as her selection for NASA’s astronaut program in 1987. Each of the key points will be marked by an LED that will be programmed to light up in the sequence of events in Jemison’s life. To do so, students will have to figure out how long each LED should stay on and how much time should elapse before the next light turns on.

Timeline design

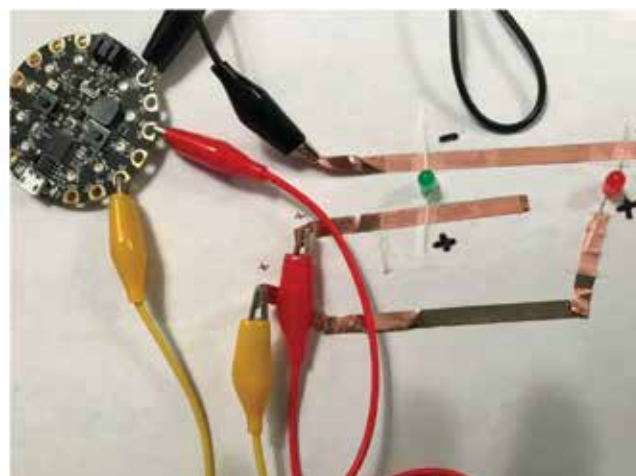
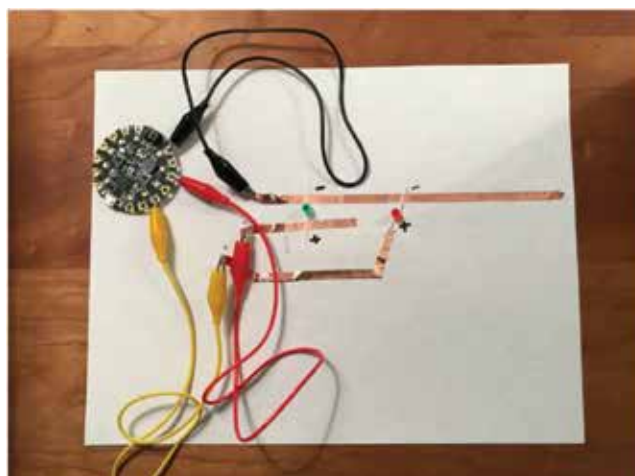
Students sketch both an artistic version of what they intend their timeline project to look like and a labeled circuit diagram illustrating how they will create functional circuits out of copper tape (see Figure 1). While there

are limited options for creating a functional circuit, designing the circuit to work with the artistic design requires inquiry on the part of students. Teachers need to approve students’ circuit schematics before they move onto the next step to make sure the circuitry is connected correctly.

Circuit construction

After getting a design schematic drawn, students work on creating their timeline. While some artistic elements may need to be drawn before the timeline is laid out, we strongly suggest students work on the artistic elements after the circuit is complete. Following their circuit diagram, students first lay out their negative line, which runs underneath the negative lead (cathode) of each LED, and attach it to the microprocessor at a ground (GND) port. Second, they lay down each of their positive leads (anodes) and attach them to the microprocessor, using

FIGURE 2: Left: one possible microcontroller that could be used for this project—the Circuit Playground Express by Adafruit. Right: lines of copper tape attached to the microcontroller using alligator clips.



alligator clips between the tape and the microcontroller (better for reuse of the microprocessors later) or by connecting the tape directly to the microprocessors by either looping it through the hole on the microcontroller or folding the sticky side over on itself to create a sort of tail that can touch the microcontroller. Each positive line will attach to a separate port on the microcontroller. Third, with the positive and negative lines in place and attached to the microprocessor, students can add detailed elements to their drawing. The process of creating the circuit is similar to the creation of circuits in the initial inquiry activity. Students simply need to follow their labeled circuit diagram to make the appropriate connections. Now that the circuit is constructed, students must code their microprocessors to allow the light bulbs to turn on in the sequence they desire. Figure 2 shows one possible microcontroller that could be used for this project, the Circuit Playground Express by Adafruit, and how to attach lines of copper tape to the microcontroller using alligator clips.

Coding the microprocessor

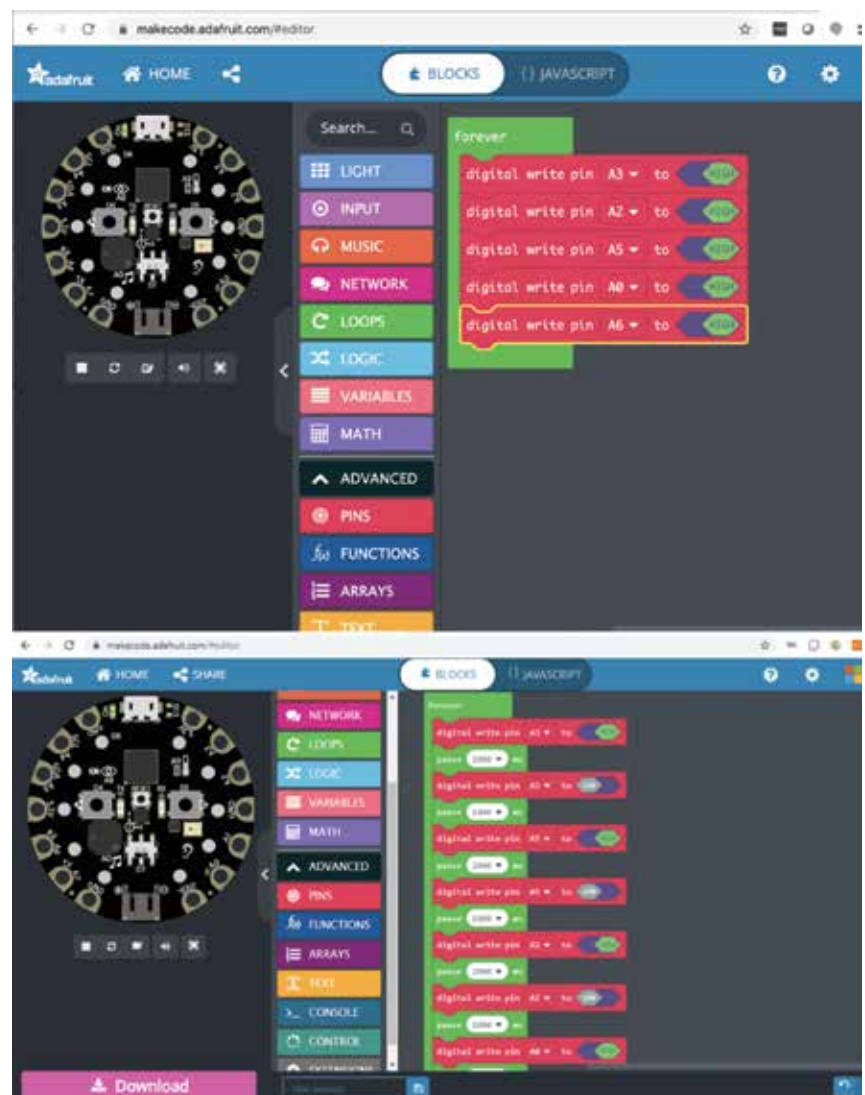
The coding in this project should be easily completed by students with no programming experience, provided a microprocessor like the Circuit Playground Express that works with a blocks-based language is used. Text-based languages can be more challenging and are better suited to students with some programming experience. We suggest guiding students

to (1) turn on all of their LEDs to confirm functional circuitry and (2) achieve a blink pattern for one of their LEDs. Figure 3 provides example code in the MakeCode environment, which works with the Circuit Playground Express microcontroller. Figure 3 shows code for (a) turning on all of the

LEDs and (b) making one LED blink in MakeCode, which works with the Circuit Playground Express microcontroller. Different microprocessors work with different coding environments.

The positive lead of each LED should be connected by an individual line of tape connected to

FIGURE 3: Sample code for [top] testing to make sure all the LEDs work and [bottom] programming the LEDs to blink. Because different projects will connect to different ports, the ports [e.g., A3, A5] will need to be adjusted accordingly.



an “A” port on microcontroller. The negative lead of the LED should be connected to the negative line of tape, which leads to a ground (GND) port on the microcontroller (see Figure 2). If a group’s LEDs do not all light up in Step 1, they will need to troubleshoot, looking for things like loose connections or flipped LEDs where the wrong lead is connected to the copper tape. Students can then work in their groups to figure out how to program their remaining LEDs, ideally by creating a set of step-by-step instructions (an algorithm) on paper and then translating these to the programming envi-

ronment. Extended directions for the construction and programming of these circuits are available in Online Resources.

Differentiation

There are several opportunities for teachers to differentiate for students during this project. The easiest way to differentiate is by altering the number of LEDs that students need to use. Using fewer LEDs results in a less complex project, while using more LEDs makes the project more challenging. Another way teachers can differentiate this project is to create a template of a timeline circuit for students to use in their

designs. Although this decreases the opportunities for students to be creative in their design, it also prevents some confusion. More advanced students can be challenged to do additional programming by adding sound to their timeline. Last, teachers can differentiate the readings provided to students in terms of both topics and ability level.

Integrating mathematics

When engaging students in this project, teachers can focus on proportional reasoning concepts, as outlined by the *Common Core State Standards* (CCSS-M; NGAC and CCSSO 2010; see also link in Online Resources). *Proportional reasoning* “is a way of reasoning about multiplicative situations” and is considered a “unifying theme in mathematics” (Van de Walle, Karp, and Bay-Williams 2019, p. 435). We focus on *ratios as rates* for this project. Ratios as rates involve relations between two different numbers, representing units such as time and length. When teachers engage students in the Lighting Up History Project, students use ratios to represent Jemison’s progress over time with a length model (time: length). Students can also represent ratios between milliseconds used in coding to determine when each LED lights up in sequence in relation to events in Jemison’s life in years (milliseconds: years) or the length between the LEDs (milliseconds: centimeters).

To bring forward ratio relationships in the science classroom, teachers can have students create

FIGURE 4: Demonstration of how ratios might be used in this project.

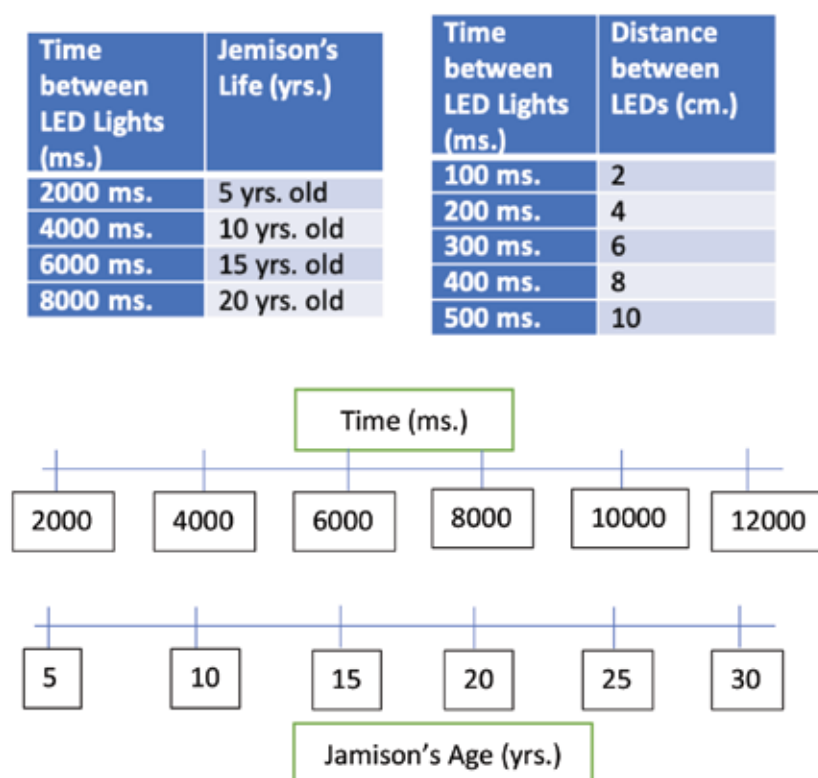


TABLE 1: Rubric for the Lighting Up History Project.

	Excellent	Satisfactory	Developing	Unsatisfactory
Timeline builder worksheet	The timeline builder worksheet is completed and reflects 5 key events in the person's life.	The timeline builder worksheet is completed and reflects 3 key events in the person's life.	The timeline builder worksheet is only partially completed and reflects less than 3 key events in the person's life.	The timeline builder worksheet is not completed.
Circuit diagram	The circuit diagram is clearly labelled, including polarity of the LEDs and ports on the microcontroller. Positive and negative connections are clearly drawn using two different colors.	The circuit diagram is only partially labeled. One or more key aspects are missing. Positive and negative connections are drawn using the same color.	The circuit diagram is minimally labeled. Two or more key aspects are missing. Positive and negative connections are missing or incomplete.	The circuit diagram was not completed or completed without attention to labelling and drawing the connections.
Circuit construction	Group members worked together to create a functional timeline while adhering to safety precautions. The timeline had LEDs representing 5 key events.	Group members worked together to create a functional timeline while adhering to safety precautions. The timeline had LEDs representing 3 key events.	Group members did not work as well together as they could have and/or safety precautions were not followed. The timeline had at least 2 LEDs representing key events.	Group members did not work together and did not follow safety precautions. One or fewer LEDs representing key events is present.
Timeline programming	Group members worked together to program the timeline. All LEDs light up in a sequence that represents the sequence of life events.	Group members worked together to program the timeline. Most LEDs light up in a sequence that represents the sequence of life events.	Group members did not work together as well as they could have to program the timeline. Only two of the LEDs light up.	Group members did not work together. The timeline was not programmed or programmed in such a way that the timeline is not functional.
Overall design	The timeline design reflects the life of the person the timeline is about. The artistic design and the circuits are thoughtfully integrated.	The timeline reflects the life of the person the timeline is about. The artistic design and the circuits are thoughtfully integrated, but could be improved upon.	The timeline does not reflect the life of the person the timeline is about as well as it could. The artistic design and the circuit design are not as well integrated as they could be.	The timeline design does not reflect anything related to the person it is about. There is no artistic design and/or circuits are completely missing.

tables where two varying units increase. For instance, if students are constructing ratio relations between milliseconds and centimeters, each column might represent changes between these units (milliseconds: centimeters) as they increase from 0:0 to 100:2 to 200:4 to 300:6 and so forth. In the science classroom, teachers can have students create a table like this before or after they make a paper circuit. The distance between the LEDs can be designed with a particular unit rate (e.g., 100:2, 50:1) in mind (see Figure 4). Supporting students during these activities might include asking questions such as, “How many milliseconds to you expect to have between LED lights at 55 years of age?” and “How does this show the relationship between years and milliseconds?” If they are struggling, teachers should focus on changes between rates that can be drawn in a tape diagram where one line represents a quantity (e.g., one foot-length line represents 55 years) and an identical line below represents a different quantity (e.g., one foot-length line repre-

sents 2,000 milliseconds). Through activities like these, students develop *composed units* where the ratio (e.g., years:milliseconds) is thought of as one unit, allowing students to understand ratio relationships without tape diagrams or other materials.

Integrating computational thinking

Students will have to evaluate multiple possible circuit designs when creating their timeline project, which connects to computational thinking and problem-solving practices. This project also asks students to engage with writing algorithms (the code to turn on their lights) and troubleshooting and debugging both their circuits and their code.

Assessment

Table 1 provides one possible rubric for summative assessment on the various components of the project. Each component of the rubric leading up to the overall design provides suggestions for formative assessment of the different project phases.

Supply list and cost

Materials for the Lighting Up History Project vary considerably in cost (see Table 2). We encourage teachers to comparison shop for the best prices. Almost any programmable, sewable microcontroller will be functional. We have tested this project in classrooms with both the LilyPad Arduino microcontroller and the Adafruit Circuit Playground Express. The microprocessors and accessories (USB cords and batteries) are the most expensive component of the project, but they can be retained by the teacher for reuse. While prices listed in Table 2 do not reflect educator discounts, most vendors offer an educator discount as well as volume pricing.

Modifying for online or hybrid learning

Because this project is supported with many video resources, it is easily adaptable to hybrid and online learning environments. Students could brainstorm at home and conduct research about their chosen scientist. Then ideally, students could complete the circuit

TABLE 2: Supplies needed by each student to complete the Lighting Up History Project.

Item	Cost/Student	Quantity/Student
Copper tape	\$0.78	8 ft.
LED bulbs	\$0.28	6-10
Coin cell battery	\$0.40	2
Circuit Playground Express microcontroller	\$24.95 [reusable year-to-year]	1
Lithium ion battery	\$5.95 [reusable year-to-year]	1
Micro-USB cable	\$1.33 [reusable year-to-year]	1
Large piece of paper or poster board	\$0.31	1

templates in the classroom or in a synchronous online session. Another option is to have students submit an online assignment for each completed circuit template so the teacher can provide feedback. Groups could collaborate on answering the following two questions based on Mae Jemison's life:

1. Describe the events from Mae's story that you are going to make your timeline about.
2. List out three to four moments/events from Mae's story that you are going to put on your timeline.

Then students could create their timeline together in the classroom. Alternatively, students could complete individual timelines at home, but this significantly increases the material costs. Programming can happen anywhere with an internet connection, though it does eventually need to be downloaded onto the microcontroller for the timeline to light up.

Conclusion

The Lighting Up History Project provides an opportunity for project-based science in the middle school classroom, with a particular focus on the integration of mathematics and computational thinking. While computational thinking has been defined in

many ways, we emphasize some of the aspects teachers can focus on, such as breaking a problem down into multiple steps, troubleshooting and debugging, and writing simple algorithms (step-by-step instructions) to turn on the timeline's LEDs. The project also allows students to learn about energy conversion (from electric to light energy), energy storage, and polarity, as well as science history.

Important safety note: The Lighting up History Project is a relatively low-risk project, but school and district safety guidelines should be followed. One concern is that the edges of the copper tape can be sharp and potentially cause a paper cut. Students should be cautioned about this possibility and work accordingly. Students will also be using scissors to cut the copper tape. Standard scissor safety precautions should be followed. ●

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ONLINE RESOURCES

- Chaos Learning Lab—<https://chaoslearninglab.weebly.com/project-e-stitch.html>
- Common Core State Standards for Math—<http://www.corestandards.org/Math/>
- CommonLit—commonlit.org
- Getting Started With Copper Tape—<https://chibitronics.com/copper-tape-tutorial/>
- Extended directions for construction and programming of circuits—<https://chaoslearninglab.weebly.com/resources.html#Video>
- Mae Jemison: Astronaut Biography—<https://www.space.com/17169-mae-jemison-biography.html>

SUPPLEMENTAL MATERIALS

Circuit templates—<https://www.nsta.org/online-connections-science-scope>

Kristin Searle (kristin.searle@Usu.edu) is an assistant professor in the Department of Instructional Technology & Learning Sciences, **Colby Tofel-Grehl** is an associate professor in the School of Teacher Education & Leadership, and **Beth L. MacDonald** is an associate professor in the School of Teacher Education & Leadership, all at Utah State University in Logan.