



Description In this math-based lesson, students build and explore different types of circuits and make calculations to gain practical skills in building, visualizing and understanding circuits.		
Grade Levels 4-6	The Tech Challenge Connections This lesson can help Tech Challenge teams build skills that aid in crafting their solutions, such as: <ul style="list-style-type: none"> • Being comfortable building circuits and confident troubleshooting them. • Understanding how to calculate total voltage of batteries in parallel and series. • Drawing a circuit diagram. 	Objectives Students will: <ul style="list-style-type: none"> • Create circuits and draw circuit diagrams. • Understand how voltage works in parallel and series circuits.
Duration Two 55-minute sessions		Standards Connections CA CCSS Math: 6—Expressions & Equations 6.EE.A.2.C Evaluate expressions at specific values of their variables.

Materials	
For circuits (Each team of 2-4 students will need a set containing all of these items)	For diagrams and calculations
<ul style="list-style-type: none"> • 2 AA batteries in a battery holder • 8 wires with alligator-clip ends • 3 E10 base bulbs (miniature screw) • 3 E10 sockets • Optional: 3V motor with fan and buzzer <p>Suggested online sources for supplies: Radio Shack, Digikey, Mouser.</p>	<ul style="list-style-type: none"> • Pencil and paper for each student • Whiteboard and markers for instructor

Prep <ul style="list-style-type: none"> • Collect materials. • If needed, build a couple of circuits yourself to get comfortable with the process.

This lesson is part of:
 The Tech Challenge, presented by Dell

For more information visit:
thetech.org/thetechchallenge



Lesson

Session 1 — Building Circuits (55 minutes)

1. Introduce circuitry engineering. (5 minutes)
 - a. Have students think of and share things in their lives that use electricity. Ask if any students have built, repaired or taken apart any of these things.
 - b. Suggested wording— *It takes practice, planning and experimentation to make devices like the ones you have listed. We are going to explore some of their inner workings and get ready to create our own by exploring and building circuits.*
2. Circuit exploration — Part 1. (20 minutes)
 - a. Give student teams three bulbs, one battery and six wires. Ask them to explore the materials and do the following challenges. Tell them to flag you down to show you once they have completed each, so you can gauge progress.
 - i. Light up one bulb.
 - ii. Light up one bulb with the fewest materials possible.
 - iii. Light up two bulbs in two different ways.
 - iv. Light up three bulbs in at least two different ways.
 - b. Educator Note: We introduce all four challenges at once so that groups can work at their own pace and still have a focus. You haven't told them how to build the circuits, so once they get to three bulbs, the circuit solutions will diverge and you won't have to worry about them working ahead and solving all the challenges.
 - c. After 5 to 10 minutes, have the students pause to talk about what they have built so far.
 - i. Take a poll to find out which challenge they are on. All groups should have finished at least challenges 1 and 2 before you proceed.
 - ii. *When you got one bulb to light up, what were the fewest components that you needed? (A power source/the battery, wires and a bulb.)* Ask a student to sketch their circuit on the board. Trace the path the electricity is taking through the circuit components to show that everything is connected to something else. (Fig. 1)
 - iii. Invite another student to modify the drawing to show what it would look like with the light off (i.e., with one wire disconnected somewhere in the circuit). Note that electricity is only flowing through the circuit when the circuit is closed.
 - iv. *Now I'm going to show you how engineers and electricians look at circuits.* Draw the same circuit with schematics. Post a key on the board for the components. (Fig. 2)
 1. Ask students why a schematic diagram might be preferable to a drawing.
 2. *Diagrams are used to communicate information about how to build a circuit regardless of which language an engineer speaks, so they can work with other engineers anywhere in the world.*
 - v. Pass out paper and pencils. *As you continue building circuits, you can check the path the electricity is taking and troubleshoot your circuit by tracing it with your finger or drawing or creating a schematic.*
3. Circuit exploration — Part 2. Parallel vs Series (10 minutes)
 - a. *Now take a few more minutes to build, so you can address challenges 3 and 4.* Circulate while the students are building and ask one group to share their parallel circuit and another to share their two-bulb series circuit. When all groups have got at least two bulbs to light up two different ways, have them stop so they can share what they have built.
 - b. Have one group share one of their two-bulb circuits by drawing a diagram on the board. Ask another group to share a different two-bulb circuit. Tell the students which is a series circuit and which is a parallel circuit. Ask the class who built a circuit like the first group and who built one like the second (hopefully all groups have built both). Ask them what differences they noticed.

Fig. 1

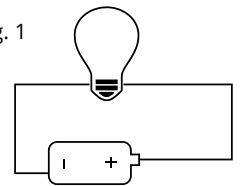
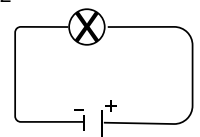


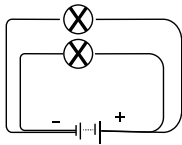
Fig. 2





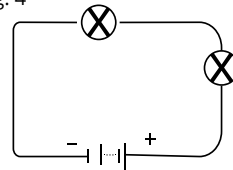
c. Parallel two-bulb circuit (Fig. 3)

Fig. 3



Series two-bulb circuit (Fig. 4)

Fig. 4



i. Be sure to share these figures if the students do not.

ii. The bulbs should have been brighter in the parallel circuit than in the series circuit. This is because there is more voltage, and therefore more current, flowing to the bulbs in the parallel circuit than the series circuit. Another difference is that the series circuit took three wires while the parallel circuit took four.

d. Explain why the series and parallel circuits are different. Use as much of the following explanation as you think students are ready for.

i. In a **series circuit**, the electricity passes through each component in a single path before returning to the power source. The current through each of the components is the same, and the voltage across the circuit is the sum of the voltages across each component.

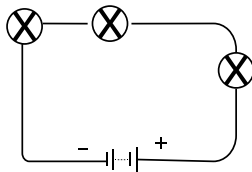
ii. In a **parallel circuit**, there are different paths for the electricity to take, so the current splits depending on the resistance of each path. The voltage across each of the paths is the same, and the total current is the sum of the currents through each component.

4. Circuit exploration — Part 3. Diagram to circuit and vice-versa (15 minutes)

a. Draw — or have the students draw, depending on their experience level — a diagram of three bulbs in series circuits and three bulbs in parallel circuits on the board.

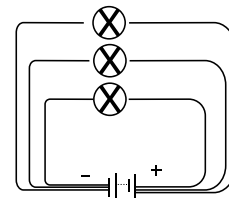
b. Three bulbs in series (Fig. 5)

Fig. 5



Three bulbs in parallel (Fig. 6)

Fig. 6



c. Tell the students that, if they have not yet built the circuits drawn on the board, they should build them at this point. The students should flag you down to show you once they have completed building each one.

d. If several or all groups have completed the circuits, have them draw a diagram of a three (or more)-bulb circuit they have built. Then, have them trade with another group and have each group build a circuit from another group's diagram. Supply teams with more wires and bulbs as needed. You may also add in other items, such as fans and buzzers, if you love noise!

5. Wrap up (5 minutes)

If you are doing The Tech Challenge with these students, have them think about how circuitry-building and diagramming will apply to their device design process and preparation. Facilitate a share-out of ideas.



Session 2 — Circuit Calculations (55 minutes)

Suggested wording: Now we're going to practice some circuit calculations that will be helpful in building circuits for your Tech Challenge designs. You will also find multiple ways to think about what is happening in your circuit (like, what is the current, voltage, watts and energy (mAh)). Many of these will depend on your circuit and its components.

1. Let's say you are building a circuit that can only use 1.5V batteries, but the maximum voltage for the circuit is 12V. So let's calculate the total voltage your batteries are supplying.

- To calculate the total voltage of the batteries in a series, simply add the voltage of each battery together. So two 1.5V batteries in series would equal 3V.
- So that was straightforward, but parallel circuits are trickier. To calculate the total voltage if your batteries are in parallel, here are a few examples:

- Two 1.5V batteries in parallel = 1.5 V. (Fig. 7)
- Two pairs of two 1.5V batteries in parallel (Fig. 8). Total $V = 1.5V + 1.5V$ so total voltage is 3V.
So the total voltage supplied by your batteries is the total of one branch of your parallel circuit. From these examples, calculate the voltage for two pairs of three 1.5V batteries in parallel. (Fig. 9).

Fig. 7

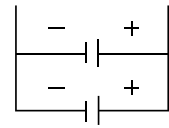


Fig. 8

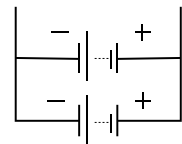
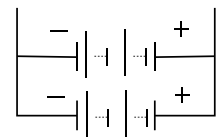


Fig. 9



- Educator Note: Share with your students if applicable. We didn't provide an example of one battery in parallel with two because that will ruin your single battery and your circuit! So if you are putting your batteries in parallel, make sure you have the same number of 1.5V batteries in each branch of your circuit.
- If you can use two 1.5V batteries in series to supply 3V to your circuit, why would you use two pairs of two 1.5V batteries (four batteries total) to supply 3V to your circuit?. Because two pairs of two 1.5V batteries in parallel will supply 3V to your circuit but will last longer! (See "How long will my batteries last?" below.)

2. Practical circuit questions

- How long will my batteries last? You can calculate the hours that your battery will last using mAh/I (milliamps hours of your batteries divided by the current in milliamps). Example: If your current is X milliamps and you have a AAA battery, then $750 \text{ mAh}/X \text{ milliamps} = Y \text{ hours}$. So for practice, let's assume the current in our circuit is 300 milliamps and use that to calculate how long each of these batteries will last. (These values are theoretical maxima; bulbs will likely last a shorter time in real life.)

AAA = 750 mAh (milliamps hour)

AA = 2,800 mAh

C = 8,200 mAh

D = 21,000 mAh

Bulb life in a 300-milliamp circuit

Battery type	mAh	Hours at 300 milliamps
AAA	750	2.5
AA	2,800	9.3
C	8,200	27.3
D	21,000	70.0

- How does the mAh in my circuit change if I have batteries in series or parallel? If you have two AAA batteries in a series, you have 750mAh at 3V. If you have two AAA batteries in parallel, you have 1,500 mAh at 1.5V. Educator note: In order to calculate the current of your circuit, students will need to use $V/R=I$.
- Will my motor (or other component) work in my circuit? On your motor or fan, look for a rating, usually in volts, and see if it is rated for the voltage you are supplying. Educator note: If you have a motor rated for a lower voltage than you are supplying, you will need resistors to make the circuit work. If you are building these circuits

LESSON PLAN: The Math Behind Circuits



with your students and do not have experience doing theoretical or practical circuit work with resistors, we recommend avoiding this situation.

3. Calculating power (watts)

You may want to calculate the power in your circuit so you don't overload your component (a fan motor, for instance). Use the calculation $2R$, or $V * I$.

4. Applying the calculations

a. Pose the following scenarios to your students.

i. *What do you think would happen if you tried to light a 60-watt light bulb using one AA battery?*

Answer: You won't be able to see any light because there isn't enough energy supplied to produce visible light.

ii. *What would you alter in this circuit to make this work?* Two possible answers: You can theoretically change to a bulb that can run off of 1.5V or use a different power supply.

iii. *What do you think would happen if you tried to run a 1.5V fan on five D batteries in a series circuit?* Answer: The circuit might get hot or explode because that is too much energy for a fan that small.

iv. *What would you alter in this circuit to make it work better?* Answer: Run using one battery or put all five D batteries in parallel.

b. Facilitate a share-out and discussion of what the students decided in their teams and what solutions they posed.

c. If you're doing The Tech Challenge with these students, have them think about how this might apply to their device design process. Facilitate a share-out of ideas.

Extensions and resources

Resources for diagramming and understanding how to calculate voltage in circuits.

Drawing circuits with series and parallel explanation:

"Circuit Symbols and Circuit Diagrams." The Physics Classroom. 2018.

<https://www.physicsclassroom.com/class/circuits/Lesson-4/Circuit-Symbols-and-Circuit-Diagrams>

Including series-parallel circuits:

"What is a Series-Parallel Circuit." All About Circuits, EETech Media.

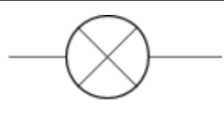

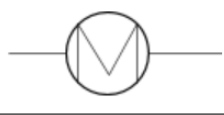
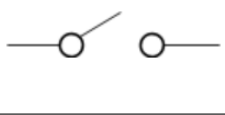

<https://www.allaboutcircuits.com/textbook/direct-current/chpt-7/what-is-a-series-parallel-circuit/>

Extension for building and diagramming circuits: Have students explore building circuits with an online simulator.

"Circuit Diagram Editor." Circuit Diagram, 2018. <https://www.circuit-diagram.org/editor/>

"Online Circuit Simulator and Schematic Editor." CircuitLab. 2018. <https://www.circuitlab.com/>

Key for component symbols

Lamp		Wire	
Motor		Open switch	
Battery		Closed switch	