What is this ACORN Physics Tutorial designed to do?

This worksheet is designed to **elicit common conceptual resources** for thinking about circuits. These resources, and examples of how they might emerge as students work through the worksheet, include:

Voltage drives current flow. Students often refer to voltage (or potential difference) as the "driver" of current flow, the agent that "creates" the current, or a "push" that the current depends on. For example, a student discussing Question 1 might say, "*The potential difference [across the plates] becomes zero, which means there's no flow. The system loses its potential difference because it's initially charged and it uses that charge until it uses up whatever initial charge it had. And then there's no flow of charge.*"

Brightness tells us something about current. Students often link the brightness of a lightbulb to current. For example, a student thinking about the circuit in Question I.D might say, "*We have two bulbs [A and D], that are in series, which are equal [in brightness]… then we have these bulbs [B and C] that are in parallel and are equal [in brightness]. I think because the question's dealing with brightness, current is really important. So A and D would have the same current, but B and C have a lesser amount of current.*"

The way the elements are connected within the circuit matters. Students sometimes reason globally about circuits. For example, if the "series- or parallel-ness" of the circuit elements change, they may infer that their resistance, voltage, current, brightness, *etc.,* will likely change as well. For example, a student thinking about the circuits in I.B might say: *"Bulbs A and B are equally bright. Since A & B are in parallel, the current divides between the two bulbs in the circuit making them dimmer than a single bulb. Therefore, C is brighter than A & B."* (Note that while this is prediction is incorrect, it still represents an inference based on the way the elements are connected.)

Current responds to changes made in the circuit. This resource is consistent with the mathematical model of current as a dependent variable. Some literature has reported that students may think of current as something that is "stored" in the battery and released at a fixed rate when the battery is connected to a circuit. In contrast, this resource models current as variable and dependent on how the circuit is constructed. For example, students discussing 1.D might say: *"Bulbs A and D dim when the switch is opened because there are now three bulbs in series rather than two bulbs in series and two in parallel. When the switch is closed, bulbs B and C are connected in parallel. This lowers their combined resistance and also lowers the total resistance of the entire circuit. With less resistance, more current can flow through the circuit. When these parallel bulbs are lost, the resistance of the circuit increases because all the bulbs are connected in series."*

Resistance limits current flow. This resource captures the sense that resistors (including light bulbs) slow or limit the flow of current or charged particles. The student discussion above provides an example.

This worksheet includes questions that elicit, refine, test, and/or build upon these ideas while at the same time leaving space for less-common ideas about electric circuits.

What content learning goals might this worksheet support?

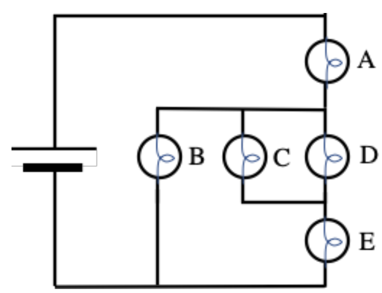
In general, ACORN Physics Tutorials are designed to support students in constructing their own models for physics concepts; the materials do not scaffold students toward a single, predetermined model. This worksheet guides students to construct a qualitative model for electric circuits that predicts the relative brightness of multiple lightbulbs arranged in various series/parallel networks with a single battery.

An example model that the worksheet could support students in constructing is:

> A. *Current splits at a junction according to how much the circuit needs, because the battery has a fixed voltage; with changes in resistance, the charge will change accordingly.*
> B. *Then when completing the circuit, the current will add all up together so that the current that's leaving the battery is the exact amount that's entering the battery. There must always be an "in" and an "out" in order to have a circuit where the flow moves in one direction.*
> C. *Batteries induce a voltage and maintain the voltage; this is why current changes so often when shifting bulbs and resistors. The current is always the "dependent variable" while voltage is constant, and resistance is independent.*
> D. *In parallel circuits, the voltage remains the same for both parallels and the current will be the same for both. When adding on a parallel, neither the voltage nor current will change for the existing parallel, but as a result, the current from the battery will double. This is where the I = V /R equation comes in, it is able to calculate how much current and therefore voltage is required.*
> E. *When in series, the current for both will be the same, however, the voltage will drop by the total voltage divided by how many equal bulbs resistors there are for each bulb. Therefore, all bulbs will have the same brightness, but individually have less brightness.*
> F. *When batteries are in sequence and in alignment, they can add together both the current and voltage they produce, if they are in sequence but not aligned, then they will cancel each other's current and voltage and therefore the net volts and amps will be 0.*

This worksheet supports students in the developing the ability to answer questions like the following:

> In the circuit at right, the bulbs are identical and the batteries are ideal. Rank the brightness of the bulbs in the circuit at right. Explain your reasoning.
>
> *(This question is adapted from Knight, Physics for Scientists and Engineers: A Strategic Approach, Ch 31)*



What resources, equipment, or experiments are good supplements to this worksheet?

PhET's Circuit Construction Kit: DC simulation is an excellent supplement to this worksheet. Students can use the simulation to test ideas and answer questions as they move through the worksheet. We recommend that every group has the sim open on one computer or tablet throughout the activity.

What are specific strategies to help students with this worksheet?

- Keep track of questions that students express and suggest ways they can test their questions using equipment or simulations.
- Suggest new circuit arrangements as thought experiments to clarify what a student is thinking or to resolve inconsistencies in their ideas.
- Share helpful analogies, such as water flow or traffic, to support students in making sense of the behavior of bulbs in series and in parallel.
- Suggest and support students' use of visual representations for potential difference and current flow in various elements of a circuit.

What research has been done to develop and/or test this worksheet?

Learn more about the research involved in this worksheet here:
https://www.physport.org/curricula/ACORN/research#circuits