Instructor Guide: A Model for Circuits

This instructor guide gives detailed guidance for teaching the ACORN Physics circuits tutorial. For more general guidance on facilitating ACORN Physics Tutorials, see our facilitator guide.

Overview & learning goals

This ACORN Physics Tutorial provides open-ended scaffolding for students to construct a qualitative model for electric circuits that include multiple resistors arranged in various series/parallel networks with a single battery, based on research on students' generative ideas about circuits. This Tutorial supports learning goals related to both scientific practices and disciplinary content.

Students will practice:

- Constructing scientific explanations
- Generalizing their observations, prior knowledge, and explanations to construct a conceptual model
- Developing hypotheses and predictions based on a conceptual model, and testing predictions
- Refining a conceptual model on the basis of tests
- Recognizing that they already have ideas relevant to physics understandings of electric circuits

Students will articulate a model that supports them to:

- Predict and explain the relative brightness of lightbulbs in series and parallel networks
- Predict and explain how the arrangement of circuit elements affects the current through a battery
- Predict and explain the current in various branches of a circuit with light bulbs and batteries
- Predict and explain the potential difference across various circuit elements

This worksheet focuses on the process of constructing a model from one's own ideas, rather than a particular canonical model. We encourage instructors to guide students to test and refine their ideas as a scientist would, rather than to guide students toward a specific set of ideas. Students will construct a variety of models that are appropriate. Example models that students have articulated at the end of this worksheet include:

> *"Bulbs light up when there is a current going through the bulb. When there is a difference in potential, the positively charged electrons can flow through the bulb with a current that is proportional to the potential difference divided by the resistance of the bulb. The current flows from high to low voltage. This means that the potential difference on either side of the batteries and resistors that are in a circuit is what dictates the direction of current flow for the whole circuit.*
>
> *With this being said, different bulbs within the same circuit can have different levels of brightness due to having different amounts of current flowing through them. In a series circuit with identical batteries and bulbs, the current is equally distributed among all the bulbs. The voltage is based on adding the sum of all the voltages from the batteries and the resistance is based on adding the resistance of each of the bulbs. In a parallel circuit, you could have a wire after a bulb that splits current equally down two different pathways and therefore those two bulbs that are using current that has been split will be dimmer than the first bulb with access to the full current."*

> 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."*

Possible 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 is this ACORN Physics Tutorial designed to do?

This Tutorial has three major sections: the first examines current flow in a set of relatively simple circuits, the second examines potential differences in the same circuits, and the third scaffolds students' process of building a conceptual model by generalizing, connecting, and refining the ideas they articulate in the first two sections. We unpack the design of each section in the paragraphs that follow.

Section 1: Current model

The first section uses a sequence of **explain/represent**, **model**, then **predict** questions to elicit a variety of fruitful ideas about circuits and support students in articulating a preliminary model of current flow in circuits that includes their own ideas. [For further discussion of different types of questions used in ACORN Physics Tutorials, see the *Facilitator Guide*.] Section 1 is predominantly designed to elicit and connect students' ideas about current flow in circuits. The final question of this section provides an opportunity for students to make a prediction to check their ideas (the "challenge question") – up to this point, the idea is for students to write down any ideas, with the guiding assumption that these ideas will be valuable for future learning.

The first question in this worksheet are explain-style questions about a discharging capacitor, designed to elicit students' ideas about the movement of charges through a light bulb. Instructors should encourage students to give thorough explanations based on their own thinking and can ask questions to understand students' thinking in more detail. Some fruitful ideas that students commonly use in responding to the capacitor sequence include: *voltage drives current flow* (e.g., potential difference pushes or pulls charges, or more voltage means more charge movement), *brightness indicates current,* or *resistance limits current flow* (e.g., resistors, including light bulbs, slow or limit the flow of current or charged particles). Ideas like these are the first pieces of the model that students ultimately construct, and will be added to, extended, and refined in the following sections.

Next, students compare a simple circuit with a single battery and light bulb (which they explained in the previous question) to circuits with a single battery and two identical bulbs in parallel and in series. First, students use their ideas about current flow to explain why the two bulbs in parallel are just as bright as a single bulb. The parallel circuit is intentionally placed before the series circuit, because we find that it most often catalyzes in-depth, fruitful sensemaking about the current flowing through each bulb and from each battery. Students may spend significant time on this question, and should not be rushed through this section. A video example of students working through this part of the tutorial is found in this Periscope lesson.

The "explain" question is paired with a "represent" question, then a "predict" question. In these questions students articulate and refine the ideas they used to explain the parallel circuit's behavior. Instructors can check that the current flow that students trace in B.2 is consistent with their explanation in B.1; note that answers need not be canonically correct at this juncture, since we are prioritizing articulation and use of a model that students are generating. The predict question in B.3 provides an opportunity for students to test and check their ideas (for example, using the PhET DC circuits simulation) and refine them if they are inconsistent with observed ammeter readings.

Once students are satisfied with their explanation of the behavior of the parallel circuit, they move to an "explain" question about a simple series circuit, then a more complex four-bulb circuit. Students apply the ideas they used to make sense of the parallel circuit to explain the current flow in each of these circuits, and refine these and add new ideas when needed. Students are instructed to trace the current flow in each circuit, and instructors can use these diagrams to check students' ideas for consistency, and/or to visualize the model that they are working to articulate. Students can move quickly through this section – particularly the simple series circuit – if they have a well-developed explanation for the parallel circuit. While students are not explicitly directed to predict or test anything about these circuits, instructors may encourage students to test circuits like these to affirm or revise their thinking.

Common ideas that students use to explain circuit behavior in this set of questions include: *brightness indicates current, resistance limits current flow, the way the elements are connected within the circuit matters* (e.g., parallel bulbs have different resistance or split the current from the battery), and *current responds to changes made in the circuit (*e.g., when a bulb is added in parallel, more current flows from the battery) (Bauman et al. 2020, Bauman et al. 2024). These ideas are relevant and fruitful for making sense of common questions like, "Why does a battery produce twice as much current when it is connected to two bulbs in parallel?" or "How much current flows through a branch with two bulbs in series?" ideas like these are conceptual beginnings of formal relationships like Ohm's law and equivalent resistance rules. Instructors should pay attention to when and how students are using these "conceptual resources" and may suggest more complex ways to apply and extend these ideas (e.g, what if a branch with two bulbs in series is added in parallel with a single bulb?).

Modeling & Testing - The checkpoint at the bottom of page 4 is the first place students are explicitly directed to reflect on their thinking and begin constructing a model. This is challenging for students, and instructors can facilitate this process by highlighting important or recurring ideas they have heard students discussing, or drawing out connections between students' ideas. Students apply their model to predict the behavior of the circuit in question E, and they should articulate a prediction and explain why their model supports that prediction before they test it. Again, it is often challenging for students to apply their model to this new circuit, and instructors can ask guiding questions to facilitate this process. (It is important that students use their own ideas to make a prediction; it's not important that the prediction is correct.) Once students have articulated a prediction, you can encourage them to test it with the PhET DC circuits simulation.

Section 2: Voltage model

In this section students revisit the capacitor, simple circuit, and 4-bulb scenarios, explaining why the potential differences across various elements compare as they do and using the concept of potential difference to explain the brightness of bulbs in these circuits. The design of this section is nearly identical to the design of Section 1, and the suggestions given for section 1 also apply here. This section emphasizes a potential difference perspective, so ideas like *voltage drives current flow* are foregrounded. Still, all of the fruitful ideas from section 1 apply. Instructors should encourage students to check and explain how their explanations in this section are consistent with their explanations in section 1. Notice that our consistent encouragement here is for instructors to support students in a process that *they* are leading, with guidance and support; our aim is for students to have the experience of recognizing that they have–and are using–relevant ideas about circuits, and to articulate what those ideas are and refine them as they work.

Since students have already considered the circuits in this section, it should take less time for them to work through this section than the first. If students have already explained the scenarios using potential difference as they worked through questions about current, this section can be skipped.

Section 3: A conceptual model for circuits

Here, students connect, articulate, and refine the set of ideas used throughout the worksheet. This is a challenging task, and instructors may take a heavier hand to highlight important ideas and connections, ask questions to probe particular ideas that are unclear, or suggest thought experiments to test the developing model. It is important that students develop models from their own ideas (rather than instructors' suggestions), but instructors can encourage students to add to or refine their model if it does not accurately predict or explain the behavior of a circuit that they test. The example model at the top of this guide illustrates that an appropriate model incorporates several rules that apply to a variety of circuits with series and parallel branches.

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 representations for potential difference and current flow in various elements of a circuit that are consistent with your teaching; for example, suggest that students trace the current flow, draw equipotential lines, or draw representative charges throughout the circuit.
- See the *Facilitator Guide* for general strategies that apply to all ACORN Physics Tutorials.

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

We developed this tutorial based on our analysis of hundreds of students' ideas about electric circuits and tested it in university physics courses, where students used the tutorial in small groups during regular class sessions. Learn more about the research involved in this worksheet here: https://www.physport.org/curricula/ACORN/research#circuits