Foldable Circuitry, Design and Construction

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Students explore circuits made using paper and copper tape and complete a standard project to see how foldability informs function. On-level students complete this project – building a box consisting of a simple circuit with the lid functioning as a switch. Honors and AP students take what they learn by building this box and apply it to an open-ended design challenge and create their own foldable circuit.

Problem

How are do we create novel circuit designs out of low-cost, unconventional materials?

Objectives

- To investigate the use of non-standard materials in circuitry
- To apply Ohm's law and the concept of equivalent resistance to non-standard circuit design
- To relate the circuit schematic drawing to the actual circuit

Anticipated Learner Outcomes

After completing this lesson, students will be able to:

- draw a standard circuit diagram for complex circuits
- explain the importance of the use of alternative components in circuit design
- measure current and voltage on a 1D surface
- apply design principles to create a unique circuit

Standards

<u>Common Core Standards</u>

Standards for Literacy in Science and Technical Subjects 6-12

- Key Ideas and Details (11-12) 3: Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text
- Craft and Structure (11-12) 4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
- Integration of Knowledge and Ideas (11-12) 9: Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

<u>Georgia Performance Standards</u>

SCSh3. Students will identify and investigate problems scientifically.

SCSh4. Students will use tools and instruments for observing, measuring, and manipulating scientific equipment and materials.

SCSh5. Students will demonstrate the computation and estimation skills necessary for analyzing data and developing reasonable scientific explanations.

SCSh6. Students will communicate scientific investigations and information clearly.

SCSh8. Students will understand important features of the process of scientific inquiry.

SP5. Students will evaluate relationships between electrical and magnetic forces.

a. Describe the transformation of mechanical energy into electrical energy and the transmission of electrical energy.
b. Determine the relationship among potential difference, current, and resistance in a direct current circuit.
c. Determine equivalent resistances in series and parallel circuits.

Background

Most standard physics electricity curriculum designs only require students to work with the most basic equipment, and labs often do not explore much beyond the exploration of the relationship between voltage and current. Some of this is due to the cost and delicacy of electronics components. By using paper and copper tape as a substitute for wires, this lesson allows students to have a less intimidating approach to the subject – the materials are incredibly inexpensive and easy to work with, and it has the potential to allow students to make more concrete connections between real circuits and the abstract diagrams that they usually work with.

A very thorough presentation of basic paper circuits is presented here -- http://tinkering.exploratorium.edu/sites/default/files/Instructions/paper_circuits.pdf -- there's no need to re-type this information here when it is so readily available. It should be noted that for this lesson, we're choosing copper tape as opposed to any conductive inks or paints because the tape can be folded without breaking.

When working with LEDs, it is important to remember several things. Firstly, the long wire on an LED needs to be connected to the positive end of the battery. Secondly, there is a minimum voltage to light the LED, but even relatively small currents can lead to burnouts. This is why paper circuit designers tend to use watch batteries, which have limited current by design. Finally, because of the way that LEDs behave in a circuit, they are not good candidates for use in combination resistor circuits – they don't follow the equivalent resistance rules that students learn in high school. If this lesson is used to teach equivalent resistance principles, it is recommended that Stage III uses traditional light bulbs as opposed to LEDs.

Materials and Supplies

This lesson is best completed if each student group has access to a computer with Internet access. For physical supplies, students will need paper, a ruler, scissors, Scotch tape (glue is not recommended), and the following electronics supplies:

- Button cell batteries – available at any retailer that sells batteries; the author used CR2032 batteries due to wide availability
- Copper tape – the adhesive needs to be *conductive* for this activity to work properly; the author used:

https://www.amazon.com/Copper-Conductive-Adhesive-Width-Length/dp/B009KB86BU

- Component LEDs – color doesn't matter; the author used: https://www.amazon.com/Elenco-Electronics-LEDK-80-LED-Component/dp/B005GL9ENC
- Other electronics components may be used depending on the sophistication of student designs – traditional light bulbs, buzzer, speaker, fan, etc.

Plan

Prior to completing this lesson, it is assumed that students have already been introduced to Ohm's law and equivalent resistance calculations. Before beginning this activity, it would be appropriate for students to complete more "traditional" activities involving Ohm's law and standard circuit components like wires and dry-cell batteries.

On-Level Course

Stage I (~20 minutes)

Engage in whole-class discussion by reminding students of prior activities with circuits and asking questions such as, "Do circuits have to be made using wires? Do circuits have to be three-dimensional? Can you think of any examples of circuits that break these rules?" A good example to give of unconventional circuit design is a 'singing' greeting card, but encourage students to come up with others.

At this time, the instructor needs to demonstrate how to construct basic "paper circuits" using watch batteries, copper tape, and LEDs. The polarity of watch batteries and LEDs should be discussed at this point. Students should be given basic supplies and allowed to replicate the basics to make sure they know how to work with the materials before moving to the next stage.

An extremely helpful site for instructors to familiarize themselves with the workings of paper circuit design is http://tinkering.exploratorium.edu/sites/default/files/Instructions/paper_circuits.pdf

Stage II (~60 minutes)

Activity: *Build-A-Box*

**NOTE – the basic outline of this activity is taken from https://chibitronics.com/paper-gift-box-tutorial/ It is a good idea to allow students access to this website so they have assembly directions to follow if the written instructions are unclear.

Working in pairs, students need to cut out the template from Appendix A and construct the circuit by completing the Build-A-Box handout.

At the end of class, students should be asked to compare their processes with other groups and comment on their challenges.

Honors/AP Course

Stages I and II are essentially the same as the on-level course. The only difference is that less time may be needed for stage II in particular, as these students may be more comfortable working from a template.

Stage III (Class time may vary; assignment as an outside project is recommended)

Activity: *Design Your Own*

In this activity, students design their own creative circuit. Depending on the needs of the teacher and the course, this activity can be tailored in the following ways:

- Materials restrictions – consider limiting the number of bulbs and/or the voltage that students can use; restrictions work best using traditional light bulbs as opposed to LEDs or other devices
- Circuit type restrictions – this activity can be used to teach combination circuits and equivalent resistances by requiring students to create a combination circuit only (an example of this is to give a student ten traditional light bulbs and require them to build a combination circuit where all bulbs are lit when connected to a 6V lantern battery); due to the nature of LEDs, it is not recommended to restrict circuit types if using them
- Design restrictions – require a 2D or 3D design, require a folding switch mechanism, size/material restrictions (an example of this would be to require that the circuit use no more than two pieces of 8.5x11 paper)
- Measurables – this may be an opportunity for a student-designed experiment, or if equivalent resistance calculations are appropriate, those can be performed; alternately, currents and voltages can be measured to determine individual resistances or wattages

Assessment/Rubrics

Stage II Handout Solutions

10. Simple circuit

11. A switch

12. Students need to understand that they just need to touch the leads to the copper tape on one side of the LED. Take points away if they put the meter in parallel with the LED instead of series.

13. There will be various answers, but good ones include low cost, assembly ease, portability, and so on.

14. Again, there will be various answers. Some obvious limitations include the fragility of the materials, the fact that the materials seem highly specialized, and students will probably comment on any difficulties they had with assembly here.

15. Again, there will be various answers. Greeting cards, advertisements, toys, and so on.

16. Any experiment that looks at how current varies with voltage is acceptable. Note, however, that our construction has a constant voltage, so the students will need to realize this and make necessary adjustments.

Stage III Rubric Recommendations

At minimum, students should be required to turn in their circuit AND an accurate circuit diagram. If measurables are part of the assignment, those calculations should be written up appropriately. If experiments are designed, a presentation would also be an appropriate way to be assessed.

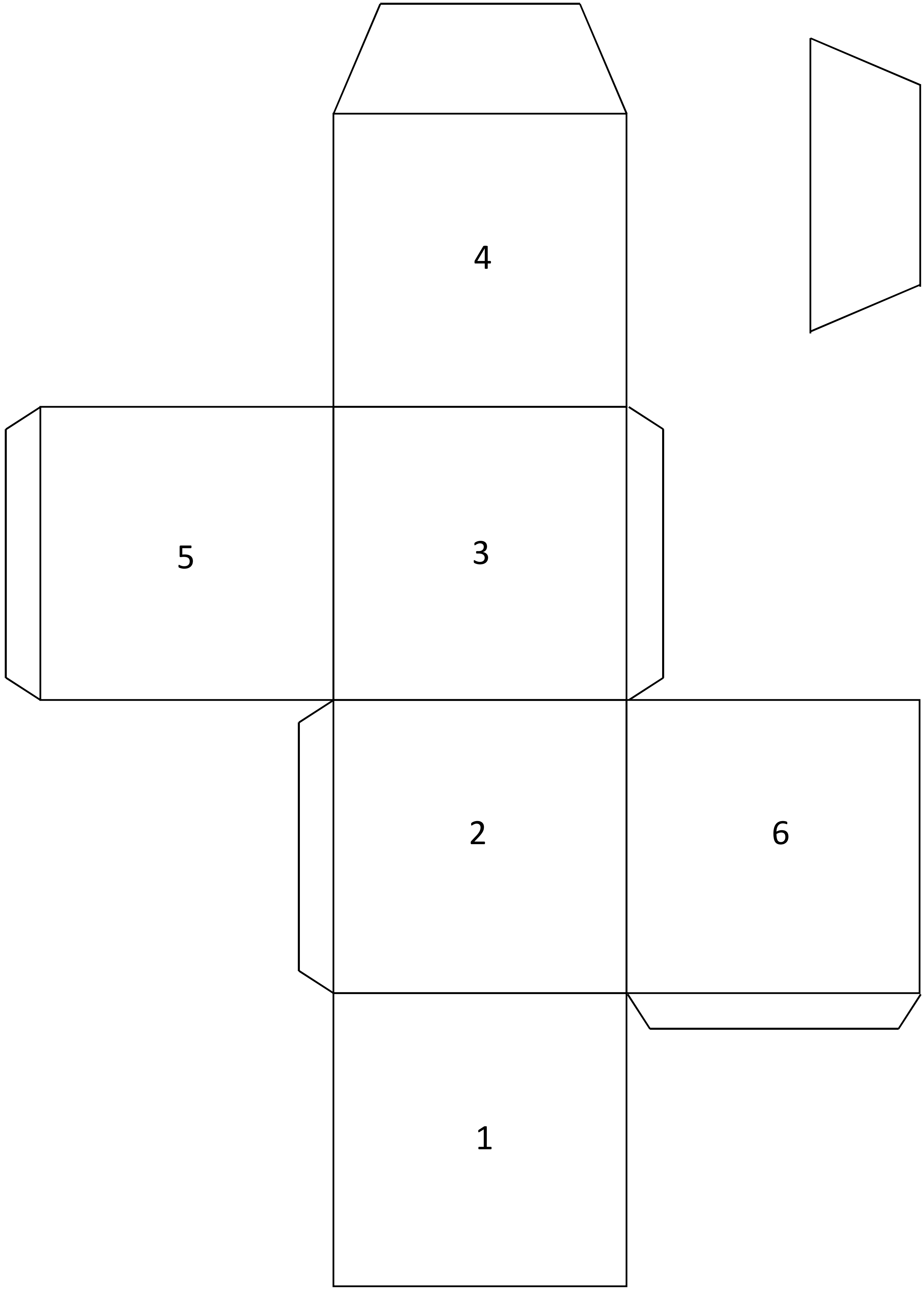
The grading suggestions here are deliberately open-ended as the project should absolutely be tailored to the individual classroom needs.

Summary

The goal of this lesson mainly is to help students understand that even the basic electricity principles they learn through the physics standards can lead to creative, innovative design and that there are electronics components beyond the standard wires and light bulbs. On-level students have the opportunity to explore these principles in a guided activity where their success will empower them to continue their explorations, and honors and AP students will be given the opportunity to take these design principles to the next level.

Supplemental Materials

Appendix A: Template for box activity
Appendix B: Handout for Stage II


4
5
3
2
6
1

Names: ____

Activity: Build-A-Box

If you need help beyond the instructions written below, feel free to visit https://chibitronics.com/paper-gift-box-tutorial/

Materials: LED, watch battery, 3 pieces of copper tape, template, scissors, Scotch tape

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Assembly

1. Cut out your template, including the second large flap. Be careful! The more evenly you cut, the better your final result will be.
2. One piece of copper tape should be placed stretching from the outside of side 1, folding over to the inside of side 1 and ending halfway onto the inside of side 2.
3. The next piece of copper tape starts on the outside of the tab above side 4 and ends halfway on the outside of side 4.
4. Fold your box on the line between sides 2 and 3 and use your scissors to make a small cut on this line just large enough to slide your third piece of copper tape in.
5. Your third piece of tape starts halfway on the outside of side 4 and continues on the outside of side 3 until you get to your cut. The tape then goes on the *inside* of side 2 – **do not peel the paper off of the part of the tape on the inside!!**
6. On the outside of side 4, there should be a gap in the middle between your two copper tape ends. The LED goes in this gap. Use some extra copper tape to attach the LED to your two ends and make sure you keep track of which end of the LED is positive – remember that this end should be connected to the top of your watch battery.
7. Start folding your box up. Before you seal off the sides with tape, place the watch battery on the inside of side 2. Use a small piece of Scotch tape to secure the battery and to secure the unpeeled copper tape to the battery. You may want to double-check that your battery is in the correct orientation by completing the loop and making sure your LED lights up – if it doesn't, try turning the battery over!
8. On the inside of side 1, tape the second large flap – this creates a little "pocket" for your flap to fit into when you close your box.
9. Tape your box together with Scotch tape. Now, when you close the lid, your box should light up!

Analysis

10. What type of circuit have you just built? Draw a circuit diagram.

11. What function does the lid flap serve in our circuit? *HINT: This answer is just one word!*

12. Explain how to measure the current in the LED with a multimeter. In your explanation, state how this measurement would be different in a traditional circuit made using wire.

13. List at least two *advantages* to using materials like copper tape and paper to build a circuit.

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14. List at least two *drawbacks* to using materials like copper tape and paper to build a circuit.

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15. List at least two ways this type of circuit design could be used in the real world.

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16. **Bonus** (*Teacher Note: Bonus for on-level, required for honors/AP*). Create an experiment using your box circuit that validates Ohm's law. Describe the procedure for your experiment in the space below.