



PCK Tools

Electricity: Student Misconceptions and Strategies for Teaching

Electricity is a subject that almost all students come to school familiar with. They all experience electricity in their daily lives and consequently come to class with a myriad of preinstructional ideas about the subject. These preinstructional ideas have been widely researched and in many cases are very similar to post-instructional ideas in all age groups. While understanding students' misconceptions is a good place to start, there also is research that can guide teachers toward approaches that may help students better understand the concepts associated with electrical circuits.

Clarification of Concepts Related to Electricity

Electricity is a broad topic, and we therefore will clarify only a few concepts that may help to make sense of some of the literature on students' understanding of electricity. We suggest, however, that to understand circuits more fully, one should look into more content on atoms and subatomic particles such as electrons and protons (a few of the links listed at the end of this section have background on this content).

Flow of current through a circuit

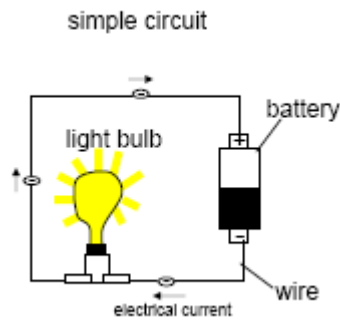
In the case of a simple circuit with metal wires, current is the flow of negatively charged electrons through the metal wires¹ (see Figure 1). The electrons flow from one end, which is negatively charged, to another end, which is positively charged because of a basic physical law of electricity that states that like charges repel and opposite charges attract. However, for electrons to flow in a circuit, there must be the following components in place:

- a source with a negative and positive end that can supply energy to allow electrical charges to move (e.g., a battery or electric generator),
- wires that lead from the positive end of the source, and back to the negative end of the source, and
- **a complete unbroken path** from the negative end to the positive end of the source. A break at any point in the circuit will prevent current from flowing and will

¹ Note that “flow” of electrons here does NOT mean that a given electron actually flows from one end to the other end of the circuit, instead there billions of electrons in a circuit found in the billions of atoms that make up the wires and these electrons collide into each other to produce a current (one analogy is to think of a traffic accident where one car hits another car from behind, which hits another car from behind, which hits another car, until the last car in the line is bumped forward).

prevent the electrical energy from being converted to any other type of energy (e.g., light energy). Hence a light bulb will not emit light without a complete circuit.

Figure 1. A Simple Circuit



Note: In the simple circuit diagram there are the following components: a battery, one wire leading to a light bulb, and a second wire going back to the battery from the light bulb. Negatively charged electrons are flowing from the negative end of the battery to the positive end of the battery.

Conservation of Energy in a Circuit

Electrical energy is the energy associated with the interaction between charged particles (analogous to how gravitational energy is the energy associated with the interaction between an object at the surface of the earth and the earth itself). Electrical energy is a type of energy, like kinetic or thermal energy, and it can be transformed to other forms of energy. Thus in an electric circuit with a light bulb glowing bright, the electrical energy associated with the charged particles in the circuit is being transformed into light

State Standards

On the topic of electricity, **the New Jersey Core Curriculum Content Standards** hold the following expectations of what middle school students should learn about and be able to do:

Grades K-4

- Demonstrate how electricity can be used to produce heat, light, and sound.

Grades 5-8

- Describe the various forms of energy including heat, light, sound, chemical, nuclear, mechanical, and electrical energy; and describe how that energy can be transferred from one form to another.

The **Texas Essential Skills and Knowledge (TEKs)** state that students must be able to do the following:

Grade 6

- Identify energy transformations occurring during the production of energy for human use such as electrical energy to heat energy or heat energy to electrical energy.
- Compare methods used for transforming energy in devices such as water heaters, cooling systems, or hydroelectric and wind power plants.

Grade 8

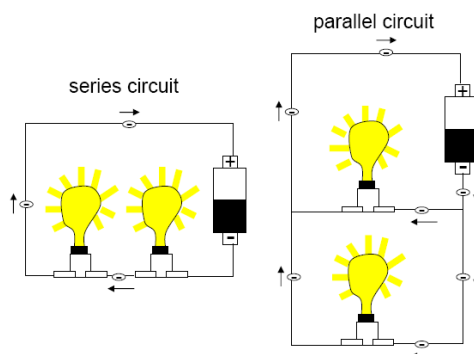
- Identify the properties of an atom including mass and electrical charge.

as well as thermal energy radiating from the light bulb. Thus, electrical energy obeys the same energy conservation laws as any other type of energy (see the Energy PCK Tool). While language such as “consumed” or “used” may be used by some engineers or scientists in connection with circuits, this does not imply that energy is actually being destroyed (as discussed in the Energy PCK Tool). Energy is simply being transformed.

Types of Circuits

Circuits can get very complex. However, there are two basic types that some curriculum units address and that some studies on misconceptions have addressed: series and parallel. In a **series circuit**, current goes in a single path. Thus a circuit with one loop and two sequential light bulbs linked together by a single wire would be considered a series circuit (see Figure 2 below). A simple circuit as described previously would fall into this category as well. In a **parallel circuit**, current can flow through more than one pathway simultaneously.

Figure 2. Types of Circuits: Series and Parallel



Note: The following are websites with more information about electricity and circuits:

<http://www.howstuffworks.com/electricity.htm>

http://www.bbc.co.uk/scotland/education/bitesize/standard/physics/electricity/series_and_parallel_circuits_rev1.shtml

<http://www.glenbrook.k12.il.us/gbssci/Phys/Class/circuits/circuitstoc.html>

Student Conceptions of Electric Circuits

Significant research has been conducted over the past 30 years documenting student misconceptions about how simple circuits work and the nature of current. The age span of the research around student conceptions is wide, covering elementary, middle, and high school, collegiate, and post-collegiate levels.

When Tiberghien and Delacôte (1976) asked children aged 7 to 13 to light a bulb given a battery, bulb, and wire, they usually created “unipolar” models. In the unipolar model, students describe electricity or electric current as moving from the battery to the bulb, where it is consumed by the bulb. This is also referred to as the “source-consumer” model.

Osborne and Freyberg (1985) identified four models, identified below, that students hold regarding simple circuits, all of which have been confirmed by numerous researchers.

1. **The unipolar model.** As stated above, students think of only one wire between the battery and the bulb as being required to light the bulb. Even if they recognize the need for a complete circuit, students will often think of the second wire as playing some minor role.
2. **The clashing currents model.** Here, students think of current as flowing from both terminals of the battery to the bulb, where they meet.
3. **The current consumed model.** Here, the current flows in one direction but is used up by the bulb so that the wire after the bulb has less current.
4. **The scientists' model.** Where current is conserved.

Each of these models is held by students of all ages, but the prevalence of each model varies with age. Most students abandon the unipolar model by the time they reach middle school. Osborne and Freyberg (1985) found that while almost 40% of 12-year-olds used the clashing currents model, this number fell to less than 10% with 15-year-olds. Shipstone (1985) found that almost 50% of 12-year-olds used the current consumed model, but this number dropped to 40% with 17-year-olds. In the same study, Shipstone found that only 10% of 12-year-olds, less than 40% of 15-year-olds, and 60% of 17-year-olds used the scientific model.

In a later study, Shipstone and colleagues (1988) administered a test on electricity in five European countries to more than 1,200 10th-grade students after instruction on electricity. The commonalities across the group are striking given the variety of school systems at which students studied. The following commonalities were found:

- The consumption of current model continued to be held by the majority of students.
- Students often viewed the battery as a source of current and not a source of voltage. The battery is viewed as a constant current source, independent of the circuit, with the current changing at each point in the circuit where an object (like a bulb) is met.
- Students often have difficulty with the concept of voltage or potential difference and, even after instruction, do not differentiate between voltage and current.
- Approximately 30% of students use sequential reasoning to analyze a circuit. Those elements at the beginning of the circuit influence all subsequent elements in the circuit, but an element at the end of the circuit does not influence any other part of the circuit. In this sense, the circuit is not viewed as a system, but instead as a sequence of individual pieces.
- Less than one quarter of students grasp the effect of resistors on current.

McDermott and Shaffer (1992) found similar conceptual difficulties among university-level students—both physics majors and nonmajors, before and after traditional instruction in electricity. Among them are the following:

Difficulties of a general nature:

- Students often refer to current, voltage, energy, and power inappropriately and interchangeably.
- About 55% of students did not draw complete circuits when asked to diagram how to light a bulb with a battery, bulb, and a single wire. This was *after* studying dc circuits in a calculus-based physics course.
- Many students have no experience working with simple circuits. Only 15% reported having some familiarity with batteries and bulbs.

Difficulties with the concept of electric current:

- Most students are unable to reason qualitatively or quantitatively about simple circuits. For example, given a diagram of a simple parallel circuit with five bulbs, only 10-15% of students were able to correctly predict the relative brightness of the five bulbs. This percentage is the same whether the question is asked before or after instruction. Interestingly, the same question was asked of 100 science and science-education faculty with similar results.
- Some students believe that the direction of the current or the order of the elements in a circuit matters.
- Many students believe that current is “used up” as it travels through the circuit; in other words, the concept of conservation of current is not understood.
- Many students believe the battery is a constant current source.

In addition to those difficulties mentioned above, many students also struggled with the concepts of potential difference and resistance. Again, all of the conceptual and reasoning difficulties the authors studied were equally prevalent before and after a traditional university lecture and laboratory course. Clearly, traditional instruction is not working.

Key Points on Student Misconceptions: Electricity

- Students think current is actually “consumed” or “used up” by the apparatuses connected to a circuit (e.g., a light bulb or electric motor).
- Students have the view that only one wire is needed to light a light bulb (or run a motor) in a circuit—a second wire leading back to the battery or generator is not needed.
- Students confuse and interchange the concepts of voltage, current, and power.
- Students fail to grasp that the order of elements in a circuit matters.

Strategies for Addressing Student Misconceptions

Pfundt & Duit (1994) published an extensive bibliography including about 280 studies on learning electricity and report that most studies have shown the success of physics instruction in electricity to be very limited (Duit, 1998). Given the evidence presented above of student misconceptions after instruction, this consensus is not very surprising.

Shaffer and McDermott (1992), following their research into student misconceptions, used that research to design instructional strategies aimed at improving student learning. Their strategies are published in a series of modules titled *Physics by Inquiry* and have proven more successful with teachers of physics and physical science than the traditional instruction previously reported on. Some of their strategies certainly are applicable to middle school teaching and learning as well. In general terms, their approach is to use direct experience with batteries and bulbs to guide students toward a conceptual model for an electric circuit. More specifically, they advocate starting with a qualitative approach.

Students begin by trying to light a bulb with a battery and a single wire. From this, students come up with a list of necessary conditions for lighting a bulb. Here the concept of a complete circuit is introduced, and by examining the internal structure of a light bulb, students begin to understand the path of current. Circuit diagrams are then introduced and examined. Next, the concept of a flow is introduced by connecting nichrome wire to the terminals of a battery. The resulting “flow” is called the electric current. The authors intentionally choose one concept to begin with and have found that introducing the concept of energy or potential difference this early on leads to complications. Gradually, students study more complex circuits. For more specific information about the lessons, see “Electric Circuits,” one of the modules featured in *Physics by Inquiry* (McDermott, 1996).

The largest area of research into learning about electric circuits focuses on conceptual change. One model for conceptual change articulated by Posner, Strike, Hewson, and Gertz (1982) argues that four conditions must exist before a conceptual change is likely to occur: (a) Students need to be dissatisfied with their current conceptions, and students need to find a new conception (b) intelligible, (c) plausible, and (d) fruitful. In theory, then,

the misconception is replaced with the new conception. Duit (1998) reports that research has shown that at best, students usually merge pieces of preinstructional conceptions and the scientific views experienced in instruction. Furthermore, students' preinstructional views often prove sufficient for dealing with electricity in daily life and are therefore difficult to give up. In one case (Gauld, 1986), three months after students appeared to accept the scientific view, most had reverted to their preteaching conceptions and had reconstructed classroom observations to support their preconceptions. Duit (1998) reports three key concerns arising out of the extensive research on conceptual change approaches for teaching students about electricity. The three concerns are:

1. *Current flow* and *energy flow* have to be clearly differentiated from the very beginning in order to address students' idea of current consumption, which has proven to withstand instruction in a very serious way.
2. *Current* and *voltage* have to be differentiated from an early stage on in order to provide students with a view of the phenomenon of current flow that includes the idea of a flow of something in a circuit and the idea of a driving "force" of that flow, but that also allows distinguishing between these issues.
3. In order to address the sequential reasoning dominating students' view of current flow, it is necessary to guide students to a "system view" of the electric circuit (Hartel, 1984) from an early stage. Whenever there is a change of some sort in one point of the circuit, there are simultaneously changes in other points also (p. 8).

Conclusion

While the research into student learning of electricity is extensive, there is no conclusive evidence to date of a single strategy that successfully brings all students to a better understanding. A good starting point appears to be an awareness of the difficulties that students have in coming to a scientific understanding. For this, there is extensive research. Second, Shaffer and McDermott (1992) have found success in beginning with a qualitative approach and guiding students to a conceptual model using very simple equipment. Finally, while some studies have shown little success using conceptual change, other studies have shown more success. While all of the above offer a starting point, there is certainly more to learn about the teaching and learning of electricity.

References

- Duit, R., & Rhöneck, C. von (1998). Learning and understanding key concepts in electricity. In A. Tiberghien, E. Jossem, & J. Barojas (Eds.), *Connecting research in physics education* (pp. 1-10). International Commission on Physics Education.
- Gauld, C. (1986). Models, meters and memory. *Research in Science Education*, 16, 49-54.
- Hartel, H. (1984). The electrical circuit as a system. In R. Duit, W. Jung, & C. von Rhöneck (Eds.), *Aspects of understanding electricity*. Proceedings of the International Workshop, Ludwigsburg, September 10-14.
- McDermott L. C. (1996). *Physics by inquiry*. Canada: John Wiley & Sons.
- McDermott, L. C., & Shaffer, P. S. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding. *American Journal of Physics*, 60(11), 994-1003.
- National Research Council (1996). *National science education standards*. Washington, DC: National Academy Press.
- New Jersey Department of Education (1996, May). *New Jersey core curriculum content standards in science*.
- Osborne, R., & Freyberg, P. (1985). *Learning in science: The implications of children's science*. Auckland and London: Heinemann.
- Pfundt, H., & Duit, R. (1994). *Bibliography: Students' alternative frameworks and science education. 4th edition*. Keil, Germany: Institute for Science Education at the University of Keil.
- Posner, G., Strike, K., Hewson, D., & Gertzog, W. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education*, 66, 211-227.
- Shaffer, P. S., & McDermott, L. C. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part II: design of instructional strategies. *American Journal of Physics*, 60 (11), 1003-1013.
- Shipstone, D. (1985). Electricity in simple circuits. In R. Dreiver, E. Guesne, & A. Tiberghien (Eds.), *Children's ideas in science*, (pp. 33-51). Milton Keynes, England: Open University Press.
- Shipstone, D. M., Rhöneck, C. von, Jung, W., Karrqvist, C., Dupin, J. J., Joshua, S., & Licht, P. (1988). A study of secondary students' understanding of electricity in five European countries. *International Journal of Science Education*, 10, 303-316.
- Tiberghien, A., & Delacôte, G. (1976). Manipulation et représentations de circuits électrique simples chez des enfants de 7 à 12 ans. *Review Francaise de Pédagogie* 34, 32-44.