Chapter 7
Designing Animated Simulations and Web-Based Assessments to Improve Electrical Engineering Education

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ABSTRACT

Over the past decade, our research group has uncovered more evidence about the difficulties undergraduate students have understanding electrical circuit behavior. This led to the development of an AC/DC Concept Inventory instrument to assess student understanding of these concepts, and various software tools have been developed to address the identified difficulties students have when learning about electrical circuits. In this chapter two software tools in particular are discussed, a web-based dynamic assessment environment (Inductor) and an animated circuit simulation (Nodicity). Students showed gains over time when using Inductor, and students using the simulation showed significant improvements on half of the questions in the AC/DC Concept Inventory. The chapter concludes by discussing current and future work focused on creating a more complete, well-rounded circuits learning environment suitable for supplementing traditional circuits instruction. This in-progress work includes the use of a contrasting cases strategy that presents pairs of simulated circuit problems, as well as the design of an online learning community in which teachers and students can share their work.

INTRODUCTION

Students often have specific difficulties understanding basic electricity concepts (e.g., Duit, et al., 1984; Caillot, 1991). One of the primary difficulties students have in learning about and understanding circuit behavior is the *current consumption model*, where current is viewed as a substance that is "consumed" by a device, such as a light bulb or resistor (Reiner et al., 2000). Students may conceive of a battery as a constant

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current source rather than a source of invariant voltage (Engelhart & Beichner, 2004). Students may also fail to differentiate between current and voltage, and power and energy (McDermott & van Zhee, 1984). Previous research has primarily been concerned with simple direct current (DC) circuit problems, and this may inadvertently guide one towards instructional decisions that reinforce misconceptions and difficulties students have when learning in other contexts. As part of an Office of Naval Research (ONR) funded project at Vanderbilt University, we extended research of student understanding of electric circuits into the domain of alternating current (AC) circuits. We were motivated by questions such as, to what extent do students exhibit the same misconceptions that they exhibit for DC circuits? How do students interpret time-varying phenomena?

Student Interviews

In interviews with students working on electrical circuit problems, we found that students had much greater difficulty understanding time-varying phenomena in circuits. We also found that students focused on manipulating formulas and performing numerical calculations during problem solving, and not applying the underlying principles or *invariants*, such as Kirchoff's or Ohm's laws, that govern circuit behavior. Analyzing common student difficulties that we identified, and by studying expert problem solving behavior, we developed a web-based tool (Inductor) for assessing and guiding students' learning of DC and AC circuits. Using Inductor we explored an additional research question: What are the effects of automated, invariants-based feedback on self-assessment and learning of electric circuit behavior? We found that by using this feedback students improved their problem solving performance in

Table 1. List of misconceptions

Misconceptions Related to AC Circuits
1. **Spatial AC misconception.** The sinusoidal AC voltage and current waveforms are not a representation of variation of these variables at a point in time. Rather they depict a variation of their magnitudes along the length of the wire in which the current is flowing. For example, students said that a string of identical light bulbs in series when connected to an AC source would light up in sequence, and some of the light bulbs may be on when others are off. At the same instant of time, the brightness of the bulbs would vary depending on their position in the circuit.
2. **Negative part of AC cycle is just a mathematical artifact.** No current flowing in circuit or power delivered during negative part of AC cycle. For example, a number of students said that a light bulb only lights up during the positive part of the sinusoidal cycle. Others said that there could be "no such thing as negative current. That is just a mathematical artifact. If current reverses, the electrons would reverse direction too. They would then run into each other, stopping flow, which implies there could be no current."
3. **Alternate form of this misconception.** The negative current "cancels" out the positive current. So bulb will never light up when you connect to true AC source.
4. **Empty pipe misconception.** During AC cycle electrons stop, turn around, and go the other way. In some cases when you have very long wires, they may never reach the light bulb connected to the end of the wire. Students thought that you would need two fuses to provide protection in an AC circuit, where you could do with one in a DC circuit.
5. Incorrectly importing DC models to explain AC. • Students often surmised that the alternating current going through a resistor was constant in time. • Students often hypothesized that a capacitor behaved the same in AC and DC circuits.
6. **Difficulties understanding circuit behavior when AC and DC signals are combined.** Students had difficulty "separating" or recognizing the AC and DC components of a signal in problems in which the midpoint of a sinusoidal voltage was not zero.
7. **More generally, difficulty thinking of circuit behavior when multiple waveforms, frequencies are combined.** Even advanced students stated that the number of channels you can got from cable TV was a function of the number of wires in the cable, or the thickness of the cable.

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