

# Work in Progress: Using the AC/DC circuits concept inventory to inform the design of a circuit simulation and instructional strategy

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**Abstract** - Over the past decade, our research group has uncovered more difficulties undergraduate students have understanding electrical circuit behavior. We have defined and refined an AC/DC Concept Inventory to assess student concepts, and based on our research we have begun developing various instructional interventions and software to address these difficulties. In this paper we will discuss the particular design decisions made for an animated circuit simulation we have constructed, and its effects on student performance on the concept inventory. Utilizing the simulation resulted in significant improvements on half of our test questions, which had particular underlying features in common. We will also discuss preliminary work on a contrasting cases strategy designed for improving student performance on the other half of our questions. In this strategy, students learn more by seeing particular pairs of circuits side by side in the simulation instead of one at a time.

*Index Terms* – circuits, concept inventory, contrasting cases, simulations

## PREVIOUS WORK

In a protocol analysis of interviews with students working on DC and AC circuit problems, we found that students had greater difficulty understanding time-varying phenomena in circuits [1]. We uncovered new misconceptions specific to AC circuits, but also found evidence of well known DC misconceptions that carried over to the AC domain. We identified a variant of the “current consumption” misconception [2] which we called the “empty pipe” model of current flow. In this model, students conceive of wires as initially “empty” when a circuit is off, and when the circuit is turned on, charges flows out from the positive terminal of the voltage source sequentially passing each circuit component. This misconception carried over to the AC domain in some students. Students would imagine current flowing out of the positive terminal during the positive section of an AC waveform, then going back into the voltage source (emptying), and coming back out the negative terminal during the negative part of the cycle. Other students even ignored behavior of the circuit during the negative parts of an AC waveform, or made no distinction

between AC and DC behavior. One other AC-specific misconception, which has similarities to previous research on graph understanding, involves students interpreting AC waveforms spatially rather than temporally. Students viewed the waveform as representing voltage changes along the wire spatially, rather than at a point in the wire over time.

## AC/DC CONCEPT INVENTORY

Based on the results of our previous research, as well as an analysis of experts’ approaches toward circuit analysis, we have developed a bank of multiple-choice test questions for assessing student difficulties with DC and AC circuits [3]. The questions focus on qualitative conceptual understanding, with both the correct answers and incorrect distracters designed to target specific invariant principles (such as Kirchoff’s laws) and misconceptions. While other circuit concept inventories have been developed since we initially created our questions (e.g., DIRECT, ECI, CCI, SSCI), our questions complement them by targeting a critical education period that bridges the high school level and the early undergraduate level, covering both DC and AC circuit concepts.

We created a 20 item multiple choice test known as the AC/DC Circuits Concept Inventory and gave this test to undergraduate engineering students *after* they had completed one or more undergraduate circuit courses. Thus the data we collected are indicative of student understanding after instruction on the circuit principles covered by this test. Students scored an average 65% correct on the test items. Overall reliability of the test as measured by the Kuder-Richardson 20 statistic (KR-20) was 0.687. Upon analyzing the pattern of responses to individual questions and inter-item correlations, we discovered two patterns:

- We found that students perform worse on temporal questions than non-temporal questions. Half (10) of the test items force students to consider the behavior of the circuit over time (temporal understanding of current), whereas the other half are non-temporal in nature. For example, question 2 asks whether one bulb lights up before another one in series when the circuit is switched on (empty pipe misconception). Other questions, however, are time invariant. For example question 1 asks if one of the bulbs was brighter than the other since

it is closer to the positive battery terminal (current consumption misconception).

- Some of the questions on our concept inventory test students' knowledge of invariant circuit principles and have distracters designed to catch misconceptions, whereas other questions test knowledge of invariant principles only. We found that performance on invariants-only questions showed more individual differences, whereas performance on misconceptions questions was relatively stable. This suggested the former are more sensitive to the effects of previous instruction on circuit principles, and re-confirms that misconceptions are more resistant to traditional instruction.

#### ANIMATED CIRCUIT SIMULATION

Based on our initial interviews and test results, we designed an animated circuit simulation to address these difficulties known as Nodicity. This simulation can model DC and AC analog circuits, including components such as capacitors and inductors and transistors. There are two major design features however that distinguish it from existing simulations. One is that current flow is visualized as a single moving chain of dashes to help students understand the behavior of the various circuits they learn in introductory classes. From interviews we found that students knew the mathematical formulas related to circuits with capacitors, for example, but could not answer basic qualitative questions such as what happens in a circuit with a capacitor, light bulb and DC voltage source. Our circuit simulation shows them this behavior. Second, our circuit simulation uses a technique known as enactive modeling [4] that allows for manipulating variables in real-time and immediately seeing their effects. Thus for example students can 'wiggle' the voltage and see its effects in a circuit with a capacitor or inductor, thereby helping students induce invariant principles related to the impedance of these components with respect to frequency changes.

#### PILOT STUDY

In a pilot study with the circuit simulation, the first author held a one hour simulation tutoring session with 40 paid volunteer undergraduate electrical engineering majors near the end of their first circuit course at Vanderbilt University. Students took the concept inventory as a pre-test and post-test. Even though this was a very short instructional intervention, students showed significant improvement on the temporal questions in the concept inventory (from 53% to 73% correct,  $F(1,77)=9.81$ ,  $p=.0025$ ). We believe this simulation is effective for addressing many of the temporal misconceptions students have about circuit behavior.

Our in progress research is exploring strategies for improving student performance on the non-temporal questions in our concept inventory. We believe part of the difficulty with these questions lies in conflating different variables (such as voltage vs. current) or a lack of distinction between components (capacitor vs. inductor) and circuit configurations (series vs. parallel). Sometimes students even ignore the fact that a circuit is AC rather than DC.

The contrasting cases strategy [5] is one technique that helps novices better notice features and make distinctions. When asked to describe the features of a circuit, a student may only attend to the superficial structure. However, when asked in the context of two slightly different circuits side-by-side, students attend to the aspects that make the two circuits differ. This strategy may help students attend to distinctions between circuit components and configurations and better understand the differences and connections between the different principles they are learning. Our current research is exploring this strategy in combination with the simulation by presenting two or more simulated circuits side by side.

#### ACKNOWLEDGMENT

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