

Rapid Conceptual Change Using an Enactive Control Interface to a Circuit Simulation

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Abstract

Previous research has identified numerous difficulties students have understanding electricity concepts, which are highly resistant to traditional instruction. In this study, students used a unique real-time control interface to an animated circuit simulation in order to enactively model how an AC voltage source controls the current flow in a circuit. In enactive modeling, the student is an agent participating in the behavior of a dynamic system and is controlling one or more temporal aspects of the changes occurring in the system. Allowing students such control during a tutoring session helped them quickly overcome many of their alternative conceptions about current and voltage, as measured by a conceptual pre and post-test and video-recorded observations.

Introduction

Scientists have routinely employed causal and mechanical models to help reason about events and communicate their understanding to other scientists (Salmon, 1998; de Regt & Dieks, 2002; Gooding, 1992), even if they later eschew these models for purely quantitative/mathematical descriptions. James Clerk Maxwell for example used a mechanical-fluid analogy for electro-magnetic fields that may have helped him deduce the quantitative relationships now known and taught as Maxwell's laws (Nersessian, 2002).

Researchers in the learning sciences and cognitive science are beginning to uncover more about the underlying basis for people's natural and informal reasoning about both physical and social events, and why people show a preference for causal and mechanical models. There appears to be a connection between our informal reasoning and the embodied nature of our thoughts and actions. We are beginning to pay attention to the role of one's body and intentional actions ("embodied cognition", "enactive learning") in order to better characterize the contextual constraints involved in natural reasoning about events. This applies to computer simulated events as well. Roth and Lawless (2001) note for example that students' "gestures are an important means in the construction of perception and communication as students interact over and about a computer software environment." They suggest that learning environments that do not support students' use of body and gesture can limit what and how students learn.

Educational researchers have found evidence linking students' kinesthetic behavior to their understanding of dynamic systems. Clement (1994) and Reiner (2000) have found that both students and experts may sometimes "describe a system action in terms of a human action" and use gestures that depict changes happening in a system. They have interpreted these "self-projections" as evidence that a person is mentally enacting or simulating aspects of a system. Monaghan and Clement (1999) observed students performing hand motions and visualizations while using a relative motion simulation. Other researchers have referred to these kinds of self-projections as anthropomorphic reasoning (Zohar & Ginossar, 1998) or anthropomorphic epistemology (Sayeki, 1989).

Sometimes these self-projections may even underlie some of the misconceptions students have in science, but they can also be used positively, as a starting point for instruction. Susan Goldin-Meadow and David Tall have found that teachers using gestures or attending to student gestures can make math instruction more effective (Goldin-Meadow, 1999; Tall, 1999, 2001; Tall & Watson, 2001; Watson &

Tall, 2002). Physics education researchers have also found that kinesthetic real-time participation is a key component responsible for the success of microcomputer-based labs (MBL) in fostering understanding of physics concepts and graph interpretation skills (Beichner, 1990; Mokros & Tinker, 1987). In MBL activities, students use computers with sensors attached (distance, force, temperature, etc.) to explore the changes that occur in physical phenomena.

Hypothesis

My hypothesis is that these kinesthetic activities are helping foster - yet also constrain - how students “intentionalize” the phenomena about which they are learning. They are connecting their natural, embodied experience of phenomena to the constraints and rules operating in scientific representations of the phenomena, and conversely, abstract scientific concepts are converted into embodied metaphors which students can use. This “exemplifies what we call symbolizing: a creation of a space in which the absent is made present and ready at hand” (Nemirovsky & Monk, 2000). More generally speaking, Roth and Lawless (2002), like Piaget, have argued that gestures can serve as a bridge between our everyday experiences in the physical world and the abstract scientific thinking that is a goal of science instruction.

If anthropomorphic reasoning, gestures, and self-projection help signify students’ understandings and misunderstandings of complex systems, then it is possible that students may benefit by instructional interventions that facilitate and constrain their enactive participation with a complex system. For this research, I explored a new learner-centered simulation design strategy that may be uniquely suited to helping students understand complex changes happening in physical systems – *enactive modeling*.

A simple example of this enactive modeling strategy has been applied in physics education. Students have difficulties understanding how Newton’s third law operates in static situations. Given a situation in which a book lies atop a table, students may recall that gravity pulls the books down, but they neglect the equal and opposite upward force that the table exerts on the book. Various strategies have been used to help students recognize this “passive” force, but an example of an enactive modeling (or enactive participation) strategy is for students to lie down on their backs and hold books up on their hands (Freudenthal, 1993). In a sense the students are enacting the role of the table and can sense that they have to push up harder if more books are added.

With more complex and simulated physical systems, however, determining how to facilitate such participation is more difficult. Most computer-based simulations are *symbolic* simulations, encapsulated representations of an external physical system such as an electric circuit. In contrast, *experiential* simulations are simulations in which the user or learner is a functional element, or agent, in the situation or system being modeled. An example of this is Model U.N., in which students from various schools take on roles of different countries in pretend meetings of the United Nations. The question I pursued though is can students learn by participating in simulations of complex *physical* systems as well as social systems. Does enacting the physical and temporal constraints that operate within a system help one understand the behavior of the system as a whole?

Application to Teaching Electrical Circuits

I applied the enactive modeling strategy to an animated simulation of electrical circuit behavior. Electricity is one of the most difficult subjects for students to understand, and there are a great deal of misconceptions about circuit behavior. Particularly difficult are behaviors that change over time, as in alternating current (AC) circuits. In an AC circuit, the voltage changes very quickly, often switching from positive to negative values. Further complicating matters, some circuit elements such as capacitors and inductors respond differently based on the rate of change in voltage or current. A

capacitor in an alternating current (AC) electrical circuit exhibits qualities similar to a resistor, a virtual impedance, but unlike a resistor, the impedance of a capacitor varies inversely with the frequency of the AC voltage source. This law of circuit behavior has consistently proved to be one of the most difficult concepts for undergraduate students to learn, and is also very difficult to represent visually or explain verbally to students. Most students may only memorize a formula or a shortcut and never understand how or why a capacitor exhibits this impedance, or how this impedance characteristic is useful for designing or troubleshooting circuits (such as radio tuners), or how it is related to other invariant constraints on circuit behavior such as Kirchoff's laws or Ohm's law.

Real-Time Control Interface

Imagine there is an interface to a circuit simulation that allows you to directly vary the voltage applied to a circuit, and the circuit responds in real-time. You could alternate the voltage from positive to negative just like an AC voltage source does, with zero voltage being the middle, or resting point. Imagine also that you could both feel the resistance of the circuit (Ohm's law), and see resistance in the form of reduced current flow. A circuit with high resistance would resist your applying voltage, and a circuit with low resistance would be easy to apply voltage. The flow of charge (current) through the circuit would also be visually depicted as an animation, to redundantly specify current and resistance.

A force-feedback steering joystick or steering wheel (commonly available as interfaces for computer games and simulations) may help students embody and understand the constraints of an AC voltage source. One may move the joystick or wheel to the right to increase the voltage positively, and to the left for negative voltages. Instead of setting the frequency of an AC voltage source by entering a numeric value or moving a slider control, students enact a change in frequency by changing how fast they move the steering wheel from side to side. The force feedback component allows one to make the joystick or steering wheel harder to move if there is a higher circuit resistance (or impedance), and easier for lower resistance. In the aforementioned AC capacitor circuit, the law governing how a capacitor's impedance varies inversely with frequency can be experienced directly, by sensing that the steering wheel is easier to move the faster you turn it and current flows faster, and harder to move and current flows slower when turned slowly or held at one position (as in a DC circuit). An inductor circuit component has the opposite relationship with frequency as a capacitor, and when combined with a capacitor may form a tuning circuit, in which there is one particular resonant frequency with the lowest resistance, or where the steering wheel turns the easiest.

Two sets of electricity misconceptions identified in earlier research also helped lead to the choice of a joystick or steering wheel for the input device to use with the circuit simulation. One set of misconceptions relates to AC circuits. Students may believe AC voltage varies spatially along a wire rather than temporally. Also, they may not understand what happens to current when voltage is in the negative part of a sinusoidal cycle. Another set of misconceptions concerns the relationship between resistance and current. For example, despite having two resistors instead of one, a parallel circuit can have lower total resistance than a circuit with only one of those resistors in series, and for many students this is counter-intuitive. Students may not even distinguish between voltage and current, and a constant voltage source versus constant current.

Research Study: Design, Methods, and Results

The study presented here tested the use of such an animated circuit simulation on individual undergraduate students, and assessed its effects of students' intuitive conceptions about circuit behavior. The study involved a mixed methods experimental design employing both quantitative and qualitative methodologies and analyses. The quantitative component consisted of a 20 item multiple

choice circuit quiz derived from other quizzes. Students took the test as a pretest and posttest. The pretest helped show what preconceptions individual students had about electrical circuit behavior coming into the study. After a individual tutorial session with the circuit simulation led by the author, students took the same test again as a post-test. This revealed how students' conceptions may have changed as a result of instruction. As will be discussed in more detail below, some students used the simulation with a joystick interface to control voltage in real-time, while a second group of students used the simulation with only an on-screen graphical slider control to change voltage. The pretest and posttest measures allow one to quantitatively compare and contrast these two groups of students, to see what effects the joystick had. Furthermore, the students were videotaped during the session while using the computer simulation, capturing the computer screen and interface devices, the student, and myself (acting as a tutor or guide) for later qualitative analysis. This allows for exploration of any potential links between particular events and actions by the student and myself to specific learning outcomes as measured by the test. With a qualitative analysis of the video, one may see if the students use gestures while using the simulation, and if there connections between what the students said or did and their developing understanding of electrical circuit behavior.

Participants consisted of 40 undergraduate electrical engineering majors recruited from introductory courses. Students were asked to volunteer to try out the animated circuit simulation during a tutoring session outside of class, and were paid approximately \$15 for participation.

The entire tutoring session with each student lasted not more than an hour. This is a very short time for an instructional intervention, however, there were two factors influencing this time decision. One is practical. Few students have volunteered in previous studies even when their only commitment was to take a couple of short quizzes online on their own time. I did not feel that keeping students in a cubicle to use the circuit simulation for much longer period of time would be desirable. Secondly, the real-time reactive control feature this simulation has that allows for controlling voltage over time is most similar in spirit to microcomputer-based labs (MBL), and research on MBL has shown surprising learning gains in very short periods of time. In MBL, students for example might move a car back and forth, while a computer graphed its motion in real-time via a sonic distance sensor. Heather Brasell (1987) has shown marked improvement in younger students' graphing skills after just 40 minutes of instruction, and Linn et al. (1987) show that this improvement asymptotes rather quickly at about the 70% level even after a year of experience with MBL. Abbott et al. (2000) actually have examined the effects of one 2-hour active learning laboratory in electrical circuits (students worked with real bulbs and circuits). They did find some significant learning gains using a pretest and posttest as well.

Results. This study showed significant conceptual change gains as well, despite the short intervention. Overall, the gains were weak, with only a 12% increase in test scores, however, eight of the twenty questions on the misconceptions test showed more significant and larger gains (highlighted in bright red in Figure 1 below). These eight questions did not have any structural characteristics in common. They included questions involving DC, DC capacitors, AC, and AC capacitor circuits. Some of the questions were very similar to the circuits explored in the simulation, and some were not (far transfer questions). What is the connection between the seemingly unrelated eight questions on which students showed significant gains? The connection appears to be that some questions on the test may force one to imagine the behavior of the circuit over time. I will show examples of this in the full paper and presentation. A post-hoc analysis identified ten questions on the test that involve considerations of circuit behavior over time. Eight of these questions are the same eight questions identified before which showed significant gains. I explain the two exceptions in the full paper. Figure 2 shows performance on these ten time related questions versus the ten which were not time related. As the graph illustrates, students did worse on time related questions on the pretest than non-time related

questions (53% vs. 68% correct, respectively). By the posttest, students answered on par in both categories (73% vs. 71% correct). Thus students showed a gain on time-related questions, yet not on non-time related questions. An ANCOVA analysis using the pretest as a covariant showed a difference between the two categories ($F(1,77)=9.81, p=.0025$).

I discuss these results as well as qualitative observations in more detail in the full paper, as well as theoretical implications for intuitive physics / misconceptions research, enactive learning, and issues in the design of educational simulations. I will discuss how the simulation is being further improved as a result of this study, and I plan to test the simulation in a real classroom during the 2006-2007 year before the AERA conference. I will also show how the enactive modeling strategy can be applied to design other learning environments including a thermodynamics simulation for learning about Charles's law, Boyle's law, and the difference between heat and temperature, about which students also often have mistaken conceptions.

Total Test Scores (N=40)

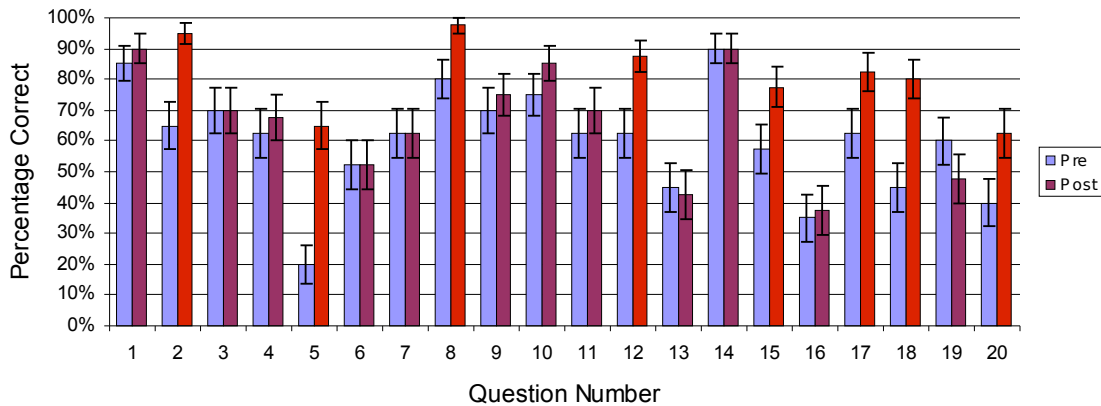


Figure 1: Scores on Individual Test Questions

Post	Correct	36	38	28	27	26	21	25	39	30	34
	Incorrect	4	2	12	13	14	19	15	1	10	6
Chi Square Result:		.2918	.0000	1.0000	.4996	.0000	1.0000	1.0000	.0000	.4652	.0765
Test Question:											
Pre	Correct	25	25	18	36	23	14	25	18	24	16
	Incorrect	15	15	22	4	17	26	15	22	16	24
Post	Correct	28	35	17	36	31	15	33	32	19	25
	Incorrect	12	5	23	4	9	25	7	8	21	15
Chi Square Result:		.3006	.0000	.7491	1.0000	.0025	.7440	.0009	.0000	.1134	.0033

Table 1: Chi Square Analysis of Individual Test Questions

Time vs. Non-Time Related Questions

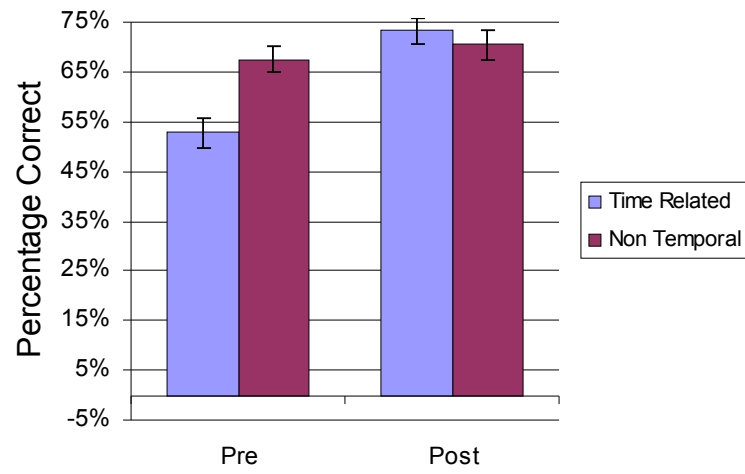


Figure 2: Time vs. Non-Time Related Questions