On Learning Electricity With Multi-Agent Based Computational Models (NIELS)

Pratim Sengupta & Uri Wilensky
Learning Sciences, Northwestern University, USA
Email: g-sen@northwestern.edu, uri@northwestern.edu

Abstract: We present NIELS (NetLogo Investigations in Electromagnetism, Sengupta & Wilensky, 2005, 2006), a multi-agent based learning environment that represents phenomena such as Electric Current, Resistance, etc in the form of *"emergent"* (Wilensky & Resnick, 1999) computational models. Based on a pilot implementation in a 7th grade classroom, we argue that NIELS models enable learners to "*think in levels"* (Wilensky & Resnick, 1999) which in turn enables them to bootstrap their existing object-based knowledge structures to engender a deep, expert-like understanding.

Section 1: Introduction

Understanding electricity requires the ability to reason about the relevant phenomena at multiple levels (Eylon & Ganiel, 1990; Gutwill, Feredriksen & White, 2000; Sengupta & Wilensky, 2006, in progress). However, students in traditional physics classrooms, after instruction, are unable to relate behavior of electrons and atoms within the wire at the microscopic level to the aggregate or macroscopic level behavior such as current, resistance, etc. Eylon & Ganiel (1990) identified this as the "missing macro-micro link" between the domains of electrostatics and electricity. To address this issue, we designed NIELS (NetLogo Investigations In Electromagnetism, Sengupta & Wilensky, 2005), a curricular unit consisting of multi-agent based models designed in the NetLogo modeling environment (Wilensky, 1999). NIELS models represent phenomena in the domain of electricity as *emergent* – i.e., aggregate-level phenomena such as electric current and resistance *emerge* from simple interactions between thousands of individual agents (electrons and atoms). Our pilot studies in a 7th grade classroom show that after interacting with NIELS, a) students are able to "think in levels" (Wilensky & Resnick, 1999) about the relevant phenomena, and b) use their existing object-based knowledge elements (that are also responsible for generating commonly noted "misconceptions" about Electricity) in order to understand and explain the relevant phenomena.

Section 2: Theoretical Framework

In their review of this literature on naïve misconceptions, Reiner, Slotta, Chi and Resnick (2000) argue that naïve reasoning is "incompatible" with that of experts and argue that the general knowledge of material substances, their properties, and how they behave is drawn on as a source of conceptual information whenever the novice encounters a difficult new physics concept. They also claim that experts use a different ontology of knowledge – "process" schemas – to make sense of phenomena in electricity. In her more recent work Chi (2005) argued that several misconceptions related to understanding complex systems cannot be remediated due to the incommensurability between common schemas about processes (for novices) and the "emergent" schema (for experts). However, other researchers (e.g., Papert, 1980; Levy & Wilensky, 2007; Sengupta & Wilensky, 2006, 2007; Blikstein & Wilensky, 2005; Wilensky & Resnick, 1999) argue that students can come to understand these emergent processes through recruiting intuitions about individuals and individual behavior, and advocate agent-based modeling as a method for enlisting these intuitions. diSessa (1993) terms this type of intuitive knowledge the *sense of mechanism*, and argues that it provides learners with the capabilities to assess the likelihood of various events based on generalizations of what does and does not happen, and causal descriptions and explanations. The visual and perceptual cues embodied in the NIELS models and activities activate object-based knowledge elements in the learners' mind, which in turn provide them with a *sense-of-mechanism* of the relevant phenomena. The rules of interactions between agents in the NIELS models correspond to simple "body-synctonic" (Papert, 1980) interactions such as push, pull and simple collisions. Students' interact with these models through a combination of simple perceptual actions (e.g., counting, observing trajectories of objects, etc.), which in turn leverage their core-knowledge systems that even research as number & motion (Spelke & Kinzer, 2007). We believe that this enables students of much younger ages (7th grade) to make sense of the phenomena that are typically taught in high school, college or beyond.

Section 3: NIELS – The Learning Environment

The models that the students interacted with are (in order): Moving Electrons, Current In a Single Wire, Series Circuit and Parallel Circuit. The first model demonstrates how electric current can emerge due to simple electrostatic interactions between individual charges. The individual-level agents in the second models are electrons and atoms inside a wire which is connected across two ends of a battery. Electrons exhibit random Brownian motion due to collisions with the atoms, and when an electric field is applied, a net drift in the direction of the applied field is superimposed on them, thereby giving rise to electric current. The rate of collisions of the "free" electrons with the atoms within the wire represents electrical resistance, while Voltage is represented in terms of concurrent electrostatic forces between the electrons and the battery terminals. In Models 3 & 4, students use their understanding of both agent-level interactions and aggregate level phenomena (from the Model 2) to understand and explain the behavior of simple electrical circuits in series and parallel.

Section 4: Methods

NIELS was implemented in a 7th grade classroom (n = 23) in a Chicago Public School in a middle-class urban neighborhood. The duration of the implementation was 8 class-periods, and the class met thrice a week. Students were administered a pre-test in the form of a written questionnaire on Day 1 and Day 8 respectively. The length of each class period was an hour, and on average, students spent 1.5 class periods interacting with each model. Students were designated to work in groups of 2 or 3, assigned randomly, and a laptop was assigned to each group. Accompanying each NIELS model are Activity Sheets that contain some relevant content knowledge, as well as instructions that scaffold students' interactions with the model. The activity sheets also provide prompts for logging their observations, reflective tasks, as well as questions that elicit mechanistic reasoning from the students. In addition, one of the researchers present in the classroom conducted short interviews with randomly selected individual students while they were interacting with the models. In these interviews, which were videotaped, students were often asked to think aloud, as well as to provide mechanistic explanations of relevant phenomena. The data from the pre- and post-tests, in-class interviews and the activity sheets were then coded in terms of a) levels (macro, micro) of description of objects and processes; and b) object-based knowledge elements and c) the contextual cues that activated these knowledge elements.

Section 5: Results

One of the most striking differences between the pre- and post-test responses of students was revealed when we asked them to draw (and label) what they expected to see if they looked inside an electrical wire which is not connected to anything. 95% of the students' diagrams in the pre-test were macro-level representations of the wire, consisting of a cross sectional view of a single wire, where they drew the outer insulating material and an inner metallic core. Only 5% of the students drew "current particles" inside the wire, and indicated that the flow of these particles as "current". In the post-test, all the students drew diagrams in which the constitutive elements were electrons and/or obstacles. 95% of the students were also able to explain voltage, resistance and electric current in terms of the micro-level agents and their interactions, compared to only 10% in the pre-test. In the transfer tasks, that involved reasoning about electric circuits from macro-level diagrams, 90% of the students were able to explain the circuit behaviors from both perspectives - micro-level and aggregate. Finally, our analysis of the process data (in-class interviews, log files, activity sheets) reveal that students were able to bootstrap their intuitive, object-based knowledge elements (e.g., P-prims (diSessa, 1993)) to engender a deep understanding of the relevant phenomena.

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