Journal of Elementary Science Education, Vol. 15, No. 2 (Fall 2003), pp. 1-11.

Hands-On Current Electricity: A Professional Development Course

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"Hands-on Current Electricity" gives K-8 teachers the opportunity to experience inquiry learning about current electricity by (1) experimenting with current electricity through a variety of activities, (2) discovering preconceived mental models of electricity used to understand their observations, (3) creating new mental models that have greater explanatory power, and (4) presenting a hands-on current electricity activity to their students as part of a final project. One teacher's intellectual growth is highlighted by means of excerpts from the teacher's weekly journal entries.

Introduction: The Challenge

Educators in the 21st century face a dilemma. Electricity powers all things electronic, from lamps and motors to stereos and computers. Everyone benefits greatly from electricity yet most of us have little understanding of it or, without realizing it, harbor alternative conceptions about it that differ from the accepted scientific conceptions (Wandersee, Mintzes, & Novak, 1994). More generally, having an appreciation of how the world around us works is akin to having an appreciation for great music, art, or literature.

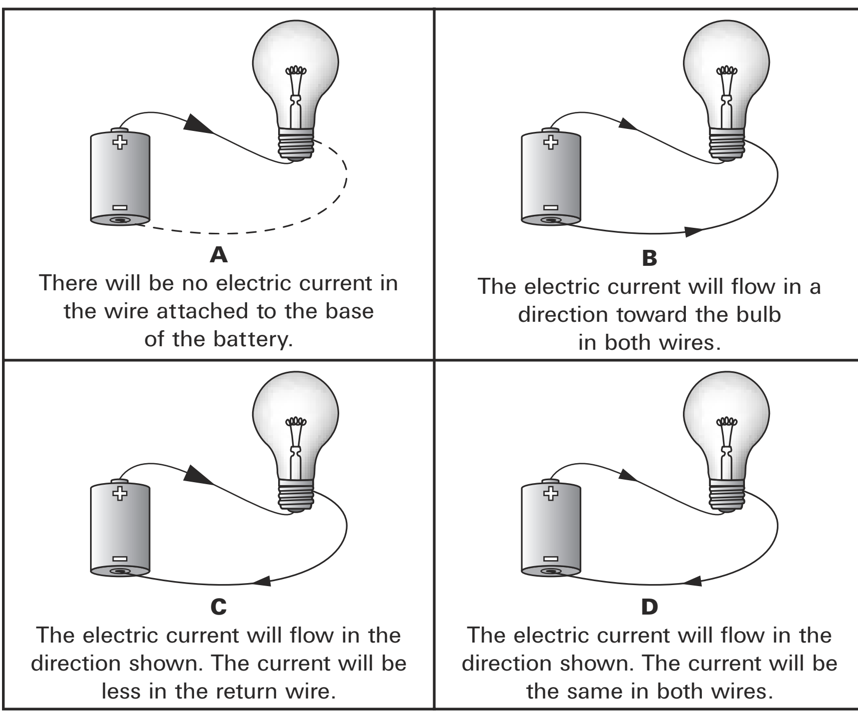
High school and college come too late for students to begin developing their understanding of electricity. By the time a student reaches high school, a good science education should give the leamer an understanding of the molecular and atomic bases of matter as noted in the *National Science Education Standards*:

> High-school students . . . move among three domains of thought—the macroscopic world of observable phenomena, the microscopic world of molecules, atoms, and subatomic particles, and the symbolic and mathematical world of chemical formulas, equations, and symbols. (NRC, 1996, p. 177)

The phenomena of electricity are easily observed by elementary students and provide evidence for the particulate nature of matter. The model for current electricity is related to and supports the atomic model for matter. Quantitative electricity and magnetism can be learned in high school and college, but the conceptual aspects of electromagnetic theory and observations of the phenomena are needed earlier when understanding of the structure of matter and of forces between objects begins to develop. It is, therefore, better to discover and learn the accepted scientific conceptions at the elementary level than to give up naive alternative conceptions (Wandersee et al., 1994) and adopt more useful ones later, at the secondary level.

Most elementary students and teachers are not familiar with electricity, with the way circuits work, and with the forces between electrically charged particles. These students and teachers bring into the classroom a variety of mental models of what happens in a circuit—their alternative conceptions. Some ideas, or pieces of models, that have come up repeatedly in interviews with students (Tasker & Osborne, 1985) are shown in Figure 1. Many are not consistent with all the observational evidence that is explained by the model (D) accepted within the scientific community. Even the simple situation depicted in Figure 1 provides evidence against one of the common models. Model A cannot explain why two wires, rather than just one, are needed. Nevertheless, our realization that energy is transferred from the battery, to the bulb, and then out from the bulb as heat and light does make model A attractive. Acquainting teachers with the body of educational research on what students think, such as the work done by Tasker and Osborne, helps teachers to assess their own and their students' knowledge. (For examples of alternative conceptions in different fields, see [mechanics]

Figure 1.
Common Ideas About Electric Current



Champagne, Klopfer, & Anderson [1980], or [astronomy] Nussbaum & Novick [1976] and Nussbaum [1979]).

Lecture, reading, and worksheet activities in grades K-8 encourage rote learning but do not change the mental models people use to interpret and manipulate their world. Even the inquiry-learning unit, Science and Technology for Children's (STC) *Electric Circuits*, a product of the National Science Resources Center (1991), develops the idea of a complete circuit but does not include the construction, criticism, and selection of mental models that explain some or all of the observations made on circuits.

Inquiry-based science curriculum at the K-8 levels can lead students to change and improve the models they use to deal with their world (Tasker & Osborne 1985; Wandersee et al., 1994). The characteristics of inquiry-based learning are described in the *National Science Education Standards*:

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (NRC, 1996, p. 23)

Despite the fact that all adults should have some understanding of basic electricity and magnetism, many K-8 teachers do not have sufficient knowledge and confidence to guide their students through an inquiry-based curriculum. They did not learn that way, and, in many cases, they did not learn enough science to teach what they are asked to teach. The NRC (2000) in its publication *Inquiry and the National Science Education Standards* states that learning in an inquiry-based curriculum . . .

> requires direct experience and continued practice with the processes of inquiry. Students do not come to understand inquiry simply by learning words such as "hypothesis" and "inference" or by memorizing procedures such as "the steps of the scientific method." They must experience inquiry directly to gain a deep understanding of its characteristics. (p. 23)

In the mid-1980s, just as the National Science Foundation was once again providing funding for science education, authors such as Kahle and Matyas (1987) examined the reasons why the inquiry-based curriculum projects developed in the 1950s and 1960s dropped out of use. They identified four barriers to the implementation of inquiry learning: the lack of (1) appropriate professional development, (2) curriculum, (3) hands-on materials, and (4) administrative support. The course we describe below attempts to enable teachers to overcome some of these barriers. To do so, teachers need to experience the learning of science by inquiry through a series of activities and reflect on that process in order to use it successfully with their students. As NRC (2000) states,

> Yet experience in itself is not sufficient. Experience and understanding must go together. Teachers need to introduce students to the fundamental elements of inquiry. They must also assist students to reflect on the characteristics of the processes in which they are engaged. (pp. 13-14)

Meeting the Challenge – Removing the Barriers

Our assault on the barriers is Education 6001, Hands-On Science for In-Service K-8 Teachers: Electricity and Magnetism. This is one of twelve courses offered for graduate credit at Washington University. The courses are part of a continuing-education certificate program in elementary science education and of a more extensive program leading to a master's degree in elementary science education. Education 6001 is a one-semester course that meets once a week for two and one-half hours for 15 weeks. We use the following nationally approved curriculum modules: *Magnets* (Delta Science Module, 1996), STC's *Electric Circuits* (NSRC, 1991), and STC's *Magnets and Motors* (NSRC, 1991). In order to be confident in their classrooms, the teachers should master the activities and understand more of the science related to them than they will teach their students. We provide materials for the teachers to take back to their classrooms (batteries, wire, bulbs, and the like), and we encourage principals to take our course with the teachers so that the principals will understand the administrative support needed.

In the course, the teachers perform hands-on activities such as the well-known batteries-and-bulbs experiments (Elementary Science Study, 1986; NSRC, 1991). We ask questions that require reflection on the phenomena observed. From this reflection the teachers and course instructors construct a table of observations (see Table 1, Column 1). We help the teachers quickly recognize the important questions, those key to developing understanding, by focusing discussion on those questions when they are asked by the teachers or by asking them ourselves. This interaction with the teachers is intense and continuous, with three instructors circulating among 24 teachers, who usually work in pairs. We use other modes of communication as well; these are discussed below.

Column 2 of Table 1 lists models from Figure 1 that cannot gracefully explain an observation. For example, Model C suggests that there is less current in a bulb close to the negative battery terminal than in a bulb close to the positive terminal. Observation eight refutes this suggestion.

The observations in Column 1 of Table 1 are not equal in complexity. For example, observations one through six require teachers to observe and describe the physical characteristics of circuits and their components. Observation seven introduces a new component, Nichrome wire, that produces an effect other than the previously observed on-or-off. At this point, teachers must become aware of and confront their mental models of electric circuits. Teachers must ask themselves what could be happening inside the circuit to account for what they observe when the Nichrome wire is added to the circuit. From this they must decide which of their observations confirm or eliminate one or more of the circulating current models shown in Figure 1. Column 2 of Table 1 summarizes the discussion of the inadequacies of Models A, B, and C to account for specific observations. In the end only model D is left, but, for teachers to understand the explanatory power of this model, they need to organize what they already know about moving objects and build analogies with what they have observed in electrical circuits.

The goals of the course are (1) to help the teachers to construct a scientific model based on a set of observations, (2) to have teachers reflect on and understand the power of the inquiry-learning approach of the course, and (3) to have them bring new content, pedagogical skills, and the necessary materials back to their classrooms to engage students in inquiry learning.

To achieve the first goal, the teachers must repeatedly make observations and formulate questions that suggest further observations. As this proceeds, important concepts are formed and named such as "circuit" and "current." Models, like those for "current" presented in Figure 1, emerge from this process. The models are judged by their ability to explain the observations economically and gracefully. These models for things that cannot be seen are understood and refined by the use of analogies with things that can be seen (Table 2). Even though each analogy

Table 1
Comparison of Observations on Circuits and Current Models in Figure 1

	Observation on a Circuit	Model(s) that Do Not Explain the Observation
1.	The curly wire, the filament, is thicker in the fat-filament bulb (a number 41 bulb) than in the thin-filament bulb (a number 48 bulb).	
2.	A metal path from the + terminal of the battery to one side of the bulb, through the curly filament to the other side of the bulb, and on to the – terminal of the battery will result in the bulb lighting.	A
3.	The fat-filament bulb is brighter than the thin-filament bulb in the circuit shown in Figure 1.	A
4.	Wood, plastic, paper, or cardboard do not complete an electrical path.	A
5.	Metal or salt water (a lot of salt) will complete a path.	A
6.	A bulb is brighter with two batteries connected with terminals + to – (in series). A bulb is not brighter with two batteries connected + to + and – to – (in parallel).	A, B, and C
7.	Nichrome wire in series with a bulb dims the bulb's glow. The longer the Nichrome wire, the dimmer the bulb. Using equal lengths of Nichrome wire, the bulb is dimmer with the thinner wire.	A, maybe B, and C
8.	In all of these observations, the position of the bulb in the circuit does not make a difference.	A, B, and C
9.	The connecting wires that complete a circuit do not glow like the filament in the bulb.	
10.	The fat-filament bulb is dark and the thin-filament bulb lights if they are connected in series.	A, B, and C
11.	A bulb in series with a diode lights if the arrow on the diode points toward the negative terminal of the battery. If either the diode or the battery is reversed, the bulb does not light. With the diode in the circuit, the bulb is not as bright as without the diode. Again, two batteries in series can make the bulb brighter with the diode in the circuit.	A, B, and C
12.	With a diode in the circuit, the relative orientation of the diode and the battery matters. Bulbs look directional because of the shapes of their bases, but by behavior and on dissection they are not.	A, B, and C
13.	After lighting a bulb for a long time, a battery wears out; moved to a new circuit, it also fails to light the new bulb. The bulb usually does not wear out; moved to a new circuit with a fresh battery, the bulb lights as before.	

is imperfect, they help the teachers find the meanings of words such as "energy," "current," "power," and "voltage." In the end, each teacher should have a well-understood mental model of what happens in circuits, one that explains all of their observations in terms of things that cannot be seen. Progress toward this final goal

Table 2
Examples of Circulating Current (Particles that Move Around a Closed Path, Gain Energy from a Source, and Lose Energy to a Sink)

Nouns Signifying Important Concepts	Visible Examples of Circulating Current			Invisible
	Human Circular Chain	Racetrack	Inclined Bed of Nails	Electricity
particle	person	car	marble	imagined electro-particle with mass and a charge of 1 coulomb
closed path or circuit	human circular chain with persons moving in one direction	racetrack filled with cars moving in one direction	bed of nails plus return path with marbles circulating	battery + connecting wire + load (Nichrome wire, tungsten filament, motor) with circulating electro-particles
current (# of particles passing a point in a unit of time)	# of persons passing a point per unit of time	# of cars passing a point per unit of time	# of marbles passing a point per unit of time	# of electro-particles (coulombs) passing a point per unit of time
energy source (type of energy)	a person handing out pretzels (stored chemical energy – fuel/food) (1 potato chip or 1 pretzel: 4.2×10^4 joules)	mechanism injecting fuel (stored chemical energy – fuel/gasoline) (1 ml of gas: 3.3×10^4 joules)	a person lifting (stored gravitational energy – increased height) (a marble lifted 1 meter: ~1×10^{-2} joules)	battery providing stored electrical energy (from a D-cell: 1.5 joules per coulomb)
resistance	effort required to turn the generator	road: roughness of surface, length, width	bed of nails: spacing of the nails, length of bed	wire: type of metal, length, width
energy sink or load (type of energy)	a person holding the generator connected to light bulb (light)	road surface (sound, temperature change in road surface)	nails on inclined bed (sound, temperature change)	Nichrome wire, tungsten filament of a bulb, motor (light, temperature change, motion)
voltage (amount of energy gained by each particle from the source in each round trip)	amount of energy gained by each person from the source in each round trip (1 potato chip or 1 pretzel: 4.2×10^4 joules)	amount of energy gained by each car from the source in each round trip (1 ml of gas: 3.3×10^4 joules)	amount of energy gained by each marble from the source in each round trip (a marble lifted 1 meter: ~1×10^{-2} joules)	amount of energy gained by each electro-particle (coulomb) from the source in each round trip (from a D-cell: 1.5 joules per coulomb)
power (amount of energy gained by the particles in a unit of time)	voltage times the current = energy transformed per unit of time	voltage times the current = energy transformed per unit of time	voltage times the current = energy transformed per unit of time	voltage times the current = energy transformed per unit of time

is not always smooth; many teachers experience confusion and frustration along the way.

To achieve the second goal, understanding the power of the inquiry-learning approach through reflection on their own learning in the course, we lead teachers to reflect on their knowledge in areas in which they have expertise. We also lead them to reflect on the nature of inquiry learning and on the ways in which they have learned about electricity and magnetism in the course. Comparing the knowledge they acquired previously and the knowledge they acquired in the course is important to their evaluation of the inquiry-learning approach used in the course. The teachers also reflect on the ways in which we guide their inquiry learning, critically judge the effectiveness of those ways, and plan the methods they will use in their classrooms.

To achieve the third goal, which is that new content, pedagogical skills, and attitudes be brought into the teachers' classrooms, the activities above must bring teachers to a level of confidence and comfort that allows them to try something new in their classrooms. We provide the necessary materials and, in exchange, ask the teachers to incorporate an inquiry-learning unit in electricity and magnetism into each of their classroom curriculums and report the results to the class. Thus, the course addresses the first three barriers identified by Kahle and Matyas (1987).

The Instructional Tools and Outcomes

In order to help teachers reflect on their mental models and reconcile them with new observations, the teachers keep a weekly journal, construct posters in class, and complete a final project. The following section illustrates the usefulness of each of these instructional tools. Vignettes from the journal of Cathy, a fifth-grade teacher, show her struggle to become aware of her model of resistance in a circuit, examine it in light of her observations, and construct the scientifically correct model of resistance based on her new understandings.

Inductive learning is hard, requires thought, and takes time (Wandersee et al., 1994). In weekly journal entries, teachers describe their perceptions of what goes on in class and reveal their struggles and progress in forming concepts and connecting observations with a model. Teachers may ask questions, clarify information, or just reflect on their understandings. Instructors read the journals carefully and write comments on each one. Through the journaling process, teachers become aware of their mental models and can reconcile prior knowledge with concepts constructed from observations made in class. Cathy's journal entries illustrate the benefits of thinking on paper and uncovering personal mental models:

> I understand the basic idea behind series (if there is a break in the circuit then all bulbs go out) and parallel (a break in the circuit doesn't necessarily mean all bulbs will go out), but was completely wrong on the idea of least resistance equaling most light.

This statement reveals Cathy's prior knowledge about the meaning of the words "series" and "parallel" as they apply to circuits and of the word "resistance" as it applies to a not yet described model in her head. Her observations in class reinforce her prior knowledge of what happens when series and parallel circuits are broken. She has yet to reconcile her observations with her "completely wrong" model of resistance. The analogies listed in Table 2 give her a way to represent what she cannot see using something she can see, thus paving the way for new understandings.

We asked teachers to reflect on the analogies presented in class and how those analogies compare with their own internal models of what happens in a circuit. After experiencing these analogies, Cathy was willing to abandon her old understanding of the meaning of the word "resistance" when she made the observations in Table 1:

> I was looking for the obvious (filament thickness, distance between filament supports, the number on the bulbs, the thickness of the wire, etc.). It took some real "playing" with the circuits, talking with Cary and Pat [a classmate and instructor, respectively], and retrying the circuits before the idea of more resistance = more energy being used = more light began making sense. Pat's examples with the . . . nail bed and marble really helped me internalize these concepts. The hands-on activity we did with pretzels being joules and having to do work as we walked the circle was very helpful. I am beginning to understand and feel comfortable (but not there yet) using the terms coulomb and joule. I don't think I can transfer this information to another problem and still be able to solve it.

Thinking of different bulbs in series, Cathy is still building toward an understanding of resistance and power. The third goal of this course is to build Cathy's confidence in her ability to transfer her understandings from one situation to another. We give teachers a safe way to try new pedagogical skills and understandings as another part of the journaling process.

Between one class meeting and the next, we ask teachers to teach what they learned in class to at least one other person and to document and assess the experience. This allows them to try their new materials, concepts, and skills with someone with whom they feel comfortable and able to take risks. Often, as Cathy reports in her journal, teachers are able to expand and extend what they learn in class, thus raising their level of confidence:

> To help me understand the idea that the amount of energy (joules) the current carries from the battery is all left in the circuit path, I think of my son and money. At the picnic when he leaves me fully charged (with money), he is able to make only one circuit (one trip to many stands) before he comes back to me (battery) empty and needs another charge (more money)!

In general, teachers who can create multiple representations, or analogies, of a concept feel that they are better able to transfer their knowledge to others.

Teachers are also asked to describe how they would teach concepts discussed in class to their own students. In her journal, Cathy documents how her growing understanding of the concepts influences her attitude about what she could teach her students:

> Last week I didn't think my fifth graders could understand this lesson, but with my better understanding, I think it could be presented in a way (like the pretzel, walk in circle, work model) that some could understand at least the basics. Any lesson I did would have to include hands-on activities so the students could identify those abstract terms with real-life events. Connecting this to real life goes with Jack's [an instructor's] thoughts that all students should know the

energy units just as they learn basic math facts and money terms. I had never given that much thought before, and I'm not sure how I feel about that. I may need a little more convincing.

Later in the semester, Cathy's journal reflects her new understandings and willingness to incorporate them into her classroom instruction when she describes her idea for her final project:

> A small group of students will play with circuits and we'll discuss how they work. As they progress, we will add correct terminology (battery, coulomb, resistance, circuit, joule). Then we will play some more to help confirm their understanding. Finally, just as we had the nailed board, human circle chain, and the racetrack models, I'll add a fourth model—the roller coaster. Students will be asked to compare the electricity model to their roller coaster model (just as we did) and correctly identify the parts of their roller coaster that correspond to the electric circuit.

Although journaling provides the opportunity for individual reflection, poster sessions allow small groups of teachers to answer specific questions, create a model or analogy to explain their observations, or present their understanding of a concept. Teachers in small groups collaborate and come to consensus about the information they put on their poster. Often, this stimulates spirited discussions and builds collegiality. Each of the groups then presents its results followed by instructors and teachers discussing each poster with the group that produced it. These discussions build an intellectually safe environment in which teachers create new knowledge through the stages of conceptualization, judgment, and reasoning. In critiquing both journals and posters, the instructors emphasize marshaling observational evidence to support models, analogies, or conclusions. Although teachers still become nervous when asked to present their posters, in general they agree that the exercise is an effective tool for moving the entire class's understanding forward.

After teachers define and refine their understandings with discussions, journals, posters, and analogies, they must produce a project that counts as a large part of their final grade. The project requires the teachers to use the curriculum materials provided in class to create and then teach a unit based on one or more concepts learned in class. Teachers have used the materials as given to them or have extended the materials, as Cathy proposed in her last journal entry. They must address classroom management issues as well. An informal survey of past teachers in the course shows that those who used the kit materials and curriculum with their students were likely to reuse the unit in subsequent years. In addition, past participants value the ease with which they can transfer what they have learned in class to their own classroom and to their colleagues. Instructors coach teachers as they design their final projects, respond to questions and challenges during the implementation of teachers' projects, and grade the final papers and oral presentations. The balance of teachers' grades come from class participation and journal evaluations.

Conclusion

The observations, discussions, journals, posters, and final projects are the instructional model through which each teacher (1) makes observations and formulates questions that beg for an explanatory model; (2) experiences and reflects upon the inquiry-learning approach; and (3) brings new content, pedagogical skills, and attitudes into the classroom, as well as the materials provided. These instructional tools help the teacher construct a scientific model of current electricity that is based on a set of observations and uses an inquiry-learning approach that mirrors professional science. The structure of the course has been designed so that it will achieve these three goals.

We claim, and have demonstrated here, three things: (1) Our experience and that of many others show that teachers have alternative conceptions, different from accepted scientific conceptions, that are difficult to change (Wandersee et al., 1994). Discussions of Figure 1 early in the course clearly display some of the alternative conceptions; (2) The alternative conceptions change only after the teachers have made and thought about a number of observations. Table 1 summarizes the observations. Cathy's journal reveals change occurring and also demonstrates how difficult it is for Cathy to make the change; and (3) The instructional model summarized in the previous paragraph facilitates conceptual change and can be taken into teachers' classrooms. Focus groups of teachers who have taken the course and our observations in some of their classrooms have confirmed this.

The instructional model does bring about conceptual change, and additionally prepares teachers to bring about the same change for their students in their classrooms.

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Manuscript accepted December 30, 2002.