How do engineering students without a strong knowledge base reason and form ideas about electricity within a task-based learning context?

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Abstract

The purpose of this study was to examine conceptions held by first year undergraduate electrical engineering students around the concepts of current, voltage, and resistance in simple and complex circuits as they enter a task-based learning environment, and how their prior knowledge interacted with their reasoning skills as they worked to solve the problems presented in the tasks. While the study involved students with both high and low knowledge, this paper focuses on two students who entered the course with low prior knowledge. The study contributed to an overall model of how students use their prior knowledge to reason within task-based learning environments and how, in turn, reasoning within a task affects their concepts.

Introduction

Task-structured curricula are anchored in a task, problem, or project, which requires student to reason across content areas rather than work through an established series of content topics. The effectiveness of task-structured curriculum has been the subject of a great deal of research, most of which has drawn ambiguous conclusions (Albanese & Mitchell, 1993). Tests of content knowledge alone sometimes show that students taught in traditional settings have a slight advantage over those taught in a task-based setting (for example, Saunders, et al., 1990), but in other cases show insignificant differences between the two groups (for example, Enarson & Cariaga-Lo, 2001). Students taught in a task-based context often show an advantage in long-term knowledge retention (Breton, 1999), and may also be better able to apply their knowledge to real-world problems (Vernon & Blake, 1993). Students engaged in problem-based learning often show a greater improvement in problem-solving skills over their traditional counterparts, as might be expected when problem solving was part of the daily problem-based learning context (Hmelo, 1998).

Inconclusive results of studies on knowledge outcomes, and possible negative consequences, have not inhibited the promotion of task-based learning as a means of teaching reform. Because of the high costs of developing and implementing task-based curricula, educators may want to know whether the methods are truly advantageous, and whether there are any disadvantageous effects.

However, the question, "Does task-based learning improve test scores?" may be the wrong question to ask. At the very least, it is overly-simplistic. Task-based learning is a very different way of learning from traditional lecture-practice-test teaching and creates different cognitive demands. It is reasonable to hypothesize that students engaged in task-based learning may be thinking, reasoning, and experiencing conceptual change differently from students in other learning contexts. Capturing these differences is often difficult, as conceptual models and reasoning skills require more than a standardized test or a survey to measure. Furthermore, any discussion of generic "students" is oversimplified, as student enter a task-based course with a wide range of prior knowledge and reasoning skills. They often work in groups where the collective knowledge allows the group to achieve tasks of greater complexity than any one member could achieve individually.

A better question to ask, then, may be: "How do student learn content knowledge and reason with that content knowledge within task-based contexts?" Answering this question requires a rich description of student learning, mental representations, conceptual change, and reasoning as students struggle with solving problems and completing tasks. as well as the dynamics involved in the social construction of knowledge. The results of many studies around these questions may then be compared with studies involving similar questions about students learning by didactic methods.

Research Questions

This study was developed to help fill the gap in knowledge about how students and reason within task-based learning contexts. Specifically, this study examined learning and reasoning among first-year electrical engineering students as they worked to complete tasks and solve problems in a project-based lab component of one of their required courses. The questions guiding the research were:

1. What phenomenographic categories of common knowledge regarding direct-current electrical circuits are constructed by first-year electrical engineering students?
2. What relationship exists between a student's prior conceptual understanding of electrical circuits and the student's reasoning processes while solving problems involving circuits?
3. How does a student's meaningful learning change as the student grapples with a series of complex problems?

This paper will look specifically at two students who entered the course with low prior knowledge.

A Proposed Model

Whitehead (1929) proposed a model of learning within a task-based setting. The knowledge that a student brings to a task consists of prior knowledge held before instruction, and any direct instruction just prior to the task. What emerges is two sets of knowledge: "meaningful" knowledge that the individual values and uses spontaneously in the task and similar tasks, and "inert" knowledge that may be recalled if asked for, such as on an exam, but is not used spontaneously. Hence "inert" and "meaningful" knowledge are related to both retention and transfer of knowledge. Figure 1 illustrates Whitehead's model.

Bransford, et al., (1993), in discussing Whitehead's propositions, argued that task-based instruction is more likely than didactic instruction to result in the development of meaningful knowledge. Bransford proposed that meaningful learning applied to tasks is retained, and is likely to be transferred to further tasks.

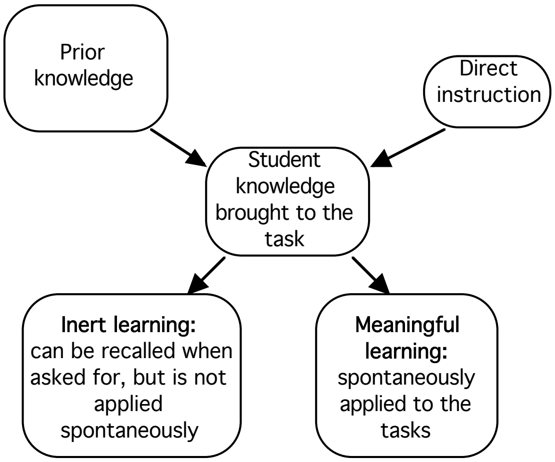


Figure 1: A diagram of learning based on Whitehead's (1929) concept of inert and meaningful learning.

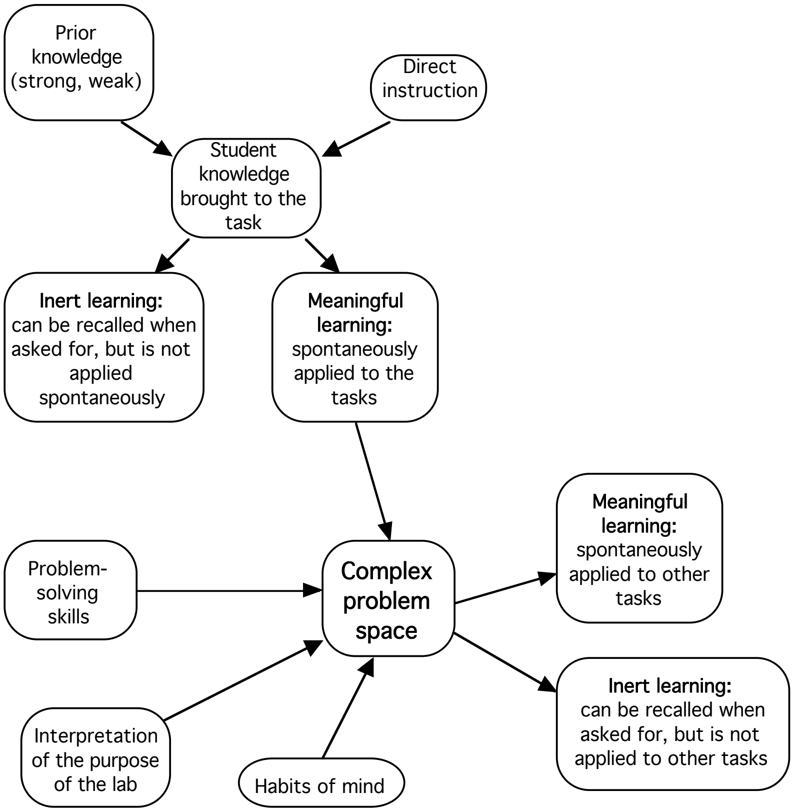


Figure 2: A proposed model of learning within task-based curricula, based on Whitehead (1929) and Bransford, et al. (1993).

Both Whitehead's and Bransford's arguments are incorporated into the model in Figure 2, which served as a hypothetical model guiding this study. This model proposes that meaningful knowledge may be discerned in two instances. First, when students enter a problem space, they bring with them a complex array of prior knowledge, some of it scientifically accurate and some of it not. Those with strong prior knowledge are often more successful at problem-solving (Anderson, 1987). Second, students may learn new knowledge in a class setting before approaching a task, depending on how the curriculum is arranged. Other factors besides enter the complex problem space. Students bring with them idiosyncratic interpretations of the purpose of the task (Osborne & Freyberg, 1985), a wide range of reasoning skills, attitudes toward the task and the subject, and habits of mind, including study skills and student self-efficacy.

The complex learning space is itself a learning environment in which students not only apply knowledge, but construct new knowledge. Emerging from this space is the student's knowledge, now transformed. Some of the resulting knowledge will be meaningful; that is, students will spontaneously apply it to further tasks. Some will be inert: the student will be able to recall the knowledge if asked, but will not think to use it on a related task. The model therefore describes an iterative process. Each time a student enters a task-based environment, the student brings the knowledge from prior learning, some of which will be applied to the new task.

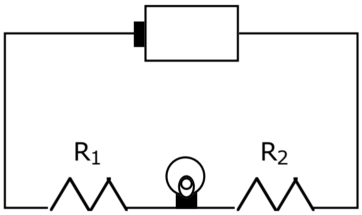
Method

This paper reports on a portion of data collected during a larger study, to be described in Bledsoe (2007), in which students with high prior knowledge and students with low prior knowledge, as determined by a survey of electrical concepts, were interviewed and observed as they participated in a task-based laboratory section of an electrical engineering course. This paper will describe two students who entered the course with low prior knowledge, how the concepts held by these students changed, the reasoning displayed by these students, and their self-perceived success in the course. These two students were of particular interest because of their differing degrees of success in the course.

The subjects of this study were selected from first-year engineering students enrolled in ECE 112: Introduction to Electrical and Computer Engineering, at Oregon State University. They were engaged in a project-based lab which involved the TekBots robotic platform (http://eecs.oregonstate.edu/education/tekbots.html), where the problem required application of knowledge of electrical systems to a series of projects as students built the robot platform, learned how it functioned, and created a "bump bot" designed to back up and turn around after it bumped into an object.

Seven case studies were selected from a pool of volunteers, and comprised students who scored at the low end and at the high end of scores on a survey of electrical concepts given on the first day of the lecture portion of the class. The survey, developed by the researcher, consisted of a set of questions on DC circuits from the concept test described in Mazur (1997) and questions drawn from McDermott & van Zee (1985) and Shipstone, (1984). Each question showed a diagram of a circuit and asked students to make one or more predictions about the circuit. Students selected from several possible answers, and wrote an explanation of their choice in the space provided. The questions were scored 2 if the student chose the correct response and gave a correct explanation, 1 for a correct response with an incorrect explanation, and 0 for incorrect or missing response and explanation. Figure 3 shows an example of a question from the survey.

5. Observe the circuit below. This circuit contains a dry cell, a bulb, and two resistors (R1 and R2).



Predict and explain the change in brightness, if any, of the bulb in each of these situations:

a. If R1 is increased the bulb will:
get brighter get dimmer stay the same

c. If R2 is increased the bulb will:
get brighter get dimmer stay the same

Figure 3: Sample question from the conceptual survey administered at the beginning and the end of this study, and used in the case study interviews.

Case study students were interviewed early in the term to develop a description of the mental conceptions they held around the concepts of current, voltage, and resistance. During the interview, students were given the survey that they had filled out. The researcher read each question and noted the student's response, then asked if the student still held that view. Students explained their responses, then were asked to create the circuit using wires, bulbs, batteries, and resistors mounted on a board in order to test their predictions. Students observed the results and attempted to explain any discrepancies.

Students were videotaped at least three times during lab as they engaged with the projects, and the researcher engaged students in conversation during lab when practical. The researcher also sat in on lectures in order to observe how students were learning concepts and what language the might be expected to use around the basic concepts.

At the end of the term, students filled out the electrical concepts survey a second time and were interviewed to develop a description of their electrical concepts at the end of the term, using the same protocols as the first interview. At this time, copies of students' lab reports were also collected.

Interviews and videotapes from labs were transcribed and analyzed using a phenomenographic perspective, using the analytical methods described in Ebenezer & Fraser (2001). Descriptions of mutually exclusive categories of knowledge were developed from student responses, and matrices developed to track whether student conceptions changed during the term. Individual student responses were used to develop a series of concept maps, which were analyzed to examine both changes in student knowledge and how students used that knowledge during the reasoning process.

Reasoning was described according to a cognitive model of reasoning by way of mental modeling, derived from Nersissian (1998). This view arises from psychological literature on semantic reasoning, which plays a larger role in human reasoning than the traditional inductive-deductive models allow (Craik, 1943). Vandierendonck and de Vooght (1996) also argue that humans tend to solve problems, including simple logic problems, by constructing mental models in memory rather than using classical rules of argument. This perspective was valuable for this study, as traditional accounts of reasoning do not support conceptual change. Nersessian (1992) argues for an explanation of conceptual change through the problem-solving process, noting that records of this process capture processes that comprise model-based reasoning. Chi, et al. (1989) and Chi (1992) employ a similar approach, using student self-explanations and "think aloud" methods as a means of tracking student reasoning and conceptual change. Reasoning and conceptual change are, in this model, intertwined, and reasoning consists largely of the application of current concepts to a specific problem.

Findings

Two of the case study students began the course with low prior knowledge. While it might be expected that students with low prior knowledge would not perform as well as students with high prior knowledge in a task-based setting, the results, as exemplified by these two students, were not that simple.

Subject AM was male, age 19. AM had studied electricity in a prior physics course, and had built his own computer, so he had some prior knowledge of electrical concepts and electronics. However, out of a possible score of 24 on the survey, AM scored 6. The highest math class that AM had taken was MTH 252, Integral Calculus.

Subject MJ was female, age 23. MJ could think of no prior courses where she had studied electrical concepts, and had no prior experience with electronics. Her score on the initial survey was 8 out of 24. However, she had an aptitude for math and had been counseled by an advisor to try electronics as a major. The highest math class that MJ had taken was MTH 256, Applied Differential Equations.

Question 1: What phenomenographic categories of common knowledge regarding direct-current electrical circuits are constructed by first-year electrical engineering students?

Transcriptions of surveys and conceptual interviews at the beginning and end of the term were examined and coded for instances of student statements regarding current, voltage, and resistance. Codes were sorted and merged to form a hierarchical set of phenomenographic categories of knowledge, which were used to describe student concept development over the course of the term.

Primary concept: the nature of current

Lecture notes provided for the class explicitly stated that current consists of electrons in motion through material. The phrase "current consists of moving electrons" was printed in bold face at the top of the class notes for the first day of class. How students interpreted and used this phrase may have depended on their understanding of what electrons are. Students who viewed them as solid particles tended to have a material view of current, while students who thought less about moving electrons and more about the effects of current tended to view current in more energetic terms. Thus two phenomenographic categories emerged:

1. Current is material or quasi-material. This view was accompanied by the belief that current could be "used up" like a fuel by circuit elements, or could even be dammed up behind resistors. The analogies used in lecture, in which current was compared to water flowing in pipes, may have reinforced this view.

2. *Current is energy*. Subjects holding this view often defined current as the flow of electrons, but when describing current in an actual circuit, tended to use energy-related terms involving the use or dissipation of energy, power, or electricity.

AM's initial conception of current was highly material. In explaining how the light bulb in the circuit board lit up, AM described light as being caused by a chemical reaction between "power" and chemicals in the bulb:

> I: Okay, so inside the bulb itself, what's happening?
> AM: The power's mixing with whatever's inside, um, the, (turns to I) the chemical that's inside it.
> I: Okay. And when you say power, what do you mean when you say power?
> AM: Electron flow. (AM, initial interview)

By the end of the term, AM's views of current still contained material elements. He talked less about current and more about voltage in the final interview, but did not distinguish clearly between the two concepts:

> AM: Um, well, say if this was like one light bulb (pointing to A and B). It would have to equal the same amount as coming into this one (pointing to C). Amount of what, I don't know. Voltage, or current. Um, so, they're going to equal the same. And, but, this one (A and B) has to divide it, because they're in parallel, so both of them are a lot dimmer than that (C). (AM, final interview)

MJ began the term with a material view of current, and struggled at the beginning of the term with the ideas that current is shown flowing one direction, while electrons flow in the opposite direction. For a student with a material view of current, this apparent conflict makes no sense:

> MJ: That's something that I'm kind of confused -- I think the electrons are going from negative to positive, but the way we always draw it is, you know, the current is always flowing from positive to -- er, I mean it's going into the positive direction, so (pauses) I'm not really sure. I think it goes like this (moving hand clockwise).
> I: So what is it that actually goes?
> MJ: Electrons.
> I: Okay, and they go...
> MJ: That's the current. (MJ, initial interview)

The only way that MJ could reconcile the two conflicting ideas was to let go of her views of flowing electrons and view current in terms if its mathematical relationships with voltage and resistance:

> It's changing the current, because the current through all three of them has to be the same because they're all in series, but the current, let's see -- since V=IR, if you increase the resistance, then the current has to go down. And if you decrease the resistance, the current has to go up. So we increased

> the resistance and the current went down, so now there's a dimmer light bulb. (MJ, final interview, explaining the effects of resistors on either side of a bulb.)

Primary concept: the nature of voltage

While students had an intuitive sense of current as something that flowed like water, voltage was a far more elusive concept. Lecture notes described voltage as an electromotive force that pushes electrons through a substance. The notes again used a water flow model, using differences in pressure at two ends of a narrow bit of hose as an analogy for differences in electrical potential on either side of a resistor. Several phenomenographic categories of knowledge emerged from student responses:

1. *No concept of voltage*. While both students described in this paper had initial concepts around voltage, two others interviewed simply had no idea of what voltage was in the initial interviews.

2. *Voltage is current or is like current*. In spite of the lecture instructor describing examples of this misconception in class, several students described voltage in current-like terms, such as describing voltage flowing through a circuit.

3. *Voltage is a measure of current*. Through instruction, students learned that voltage is not current, but some students still struggled to understand exactly what voltage was. Students used multimeters in class to measure current and voltage, and some seemed to believe that voltage was a measure of some quality of current or of current itself.

4. *Voltage is pressure or "push."* This concept was used in the lecture notes as an analogy to help students understand voltage. While not strictly scientifically accurate, it served as a useful model as students made predictions about their lab tasks and the interview tasks. This may have been drawn from the water pipe analogy, since the class notes compared voltage with measuring pressure in the pipe.

5. *Voltage is potential energy*. This concept, while more scientifically accurate, was the most difficult for students to understand. Those who described voltage as potential energy either used the "push" concept to make predictions about where current would flow, or discarded the idea of current entirely and described circuits in terms of mathematical relationships.

In the initial interview, AM seemed confused by the concept of voltage, and tended to describe voltage in terms that he also applied to current. Though he wasn't fully satisfied with this explanation, he nevertheless went back to it as he struggled to define the term:

> I: For instance, you measure voltage in lab.
> AM: Right.
> I: So what do you picture yourself measuring?
> AM: (long pause) The — number of electrons at a give moment? (Looks back at interviewer)
> I: Okay. So when it says it's such-and-such volts, or when you measure so many volts across a resistor, we're measuring electrons with them?
> AM: Uh, no. (thinks) Hm... The current would be the flow of electrons, and R, resistance is how many electrons are being held back, er, not how many, it's just, just a number. I mean, 4.7 ohms, it's not going to hold back 4.7 electrons. So yeah, I guess it makes sense that voltage would be the number of electrons. (AM, initial interview)

By the end of the term, AM realized that voltage was not current, and moved to a conception of voltage as a measure of current:

> I: Or when you were measuring voltage in lab. What was it that you felt you were measuring? ...
> AM: I'm going to say it's the change of, um, like electrons flowing. Not flowing. Just the like either the drop or the increase between one point and the other. (AM, final interview)

Early in the term, MJ was forming models of voltage as a source of pressure to move current:

> I: Yeah, basically what is it that -- that the meter's actually measuring. What is it that those numbers mean?
> M: Well, it's not measuring the current, it's measuring the pressure of the current. The um, way he explained it in class was relating it to water, where the quantity of the water is the current and then the pressure of the water is the voltage, you know, the pressure of the current. (MJ, first observation)

In the final interview, MJ had moved to talking about voltage as potential energy when asked for a definition, while her spontaneous explanations involved voltage in its mathematical relation to current and resistance:

> I: Okay, so what is voltage?
> MJ: It's the change in potential from here to here (pointing to resistor on diagram) or from here to here or wherever you're measuring it from. Change in electric potential. (MJ, initial interview)
>
> MJ: They're both getting the same voltage from the battery doing it like this. And this way the voltage to each of them can only be equal to the voltage across the battery it can't be -- and since the resistance of each of them is assumed to be equal, then this is, this (bulbs in series) can only get half of the voltage of the battery and this can get the other half. But this way (bulbs in parallel) they can each have the full voltage of the battery. (MJ, initial interview, describing series and parallel circuits.)

Primary concept: the nature of resistance

Like voltage, resistance was a difficult concept for all students. The class notes in the second week introduced the concept of resistance while introducing Ohm's Law. The notes relied on a water analogy, comparing wires to fire hoses and resistors to drinking straws: forcing the water in a fire hose through a drinking straw slows the flow of water considerably. There was also a molecular explanation involving the speed at which electrons can diffuse through materials. The target concept in the notes appeared to be *loss of kinetic ener*gy. However, However, the phrase from the notes that students appeared to assimilate the most was, "...a resistor is a component that purposefully impedes or opposes the flow of electrons." This definition was used during the lecture, indicating a target concept of impeding the flow of current.

All subjects were familiar with the phrase "the path of least resistance," and used it on an interview problem involving two bulbs wired in series, with a switch bypassing one of the bulbs. Subjects correctly predicted that the bypassed bulb would dim or go out when the switch was pressed because the switch had less resistance than the bypassed bulb. However, not all subjects predicted that the second bulb would get brighter at the same time that the bypassed bulb went out, indicating limitations to their knowledge of the effects of resistance on the circuit as a whole.

Three phenomenographic categories of knowledge emerged:

1. *Resistance is holding back of current*. This view often accompanied a material view of current. The resistor was viewed as an impediment, like a traffic cop holding back traffic, or a dam in a stream holding back water. One student, not described at length in this paper, believed that a bulb "behind" a resistor should get brighter if the resistance was increased because more current would pool behind the resistor, making more available to the bulb.

2. *Resistance is the restriction of current*. This differs from the first concept in that current is not seen as being physically held back, but that its flow is somehow restricted in its flow. In the water model analogy offered in class, resistors were compared with a narrow bit of hose, which causes an increase in pressure of the water flowing through. Students using this model thought that resistance should slow down the current.

3. *Resistance is the dissipation of energy*. While students using other descriptions sometimes spoke of energy dissipation, only one student, not described at length in this paper, used dissipation of energy as his primary means of describing resistance.

AM began and ended the term with the idea that resistance involves holding back or blocking current. Interestingly, this concept was challenged in the initial interview when AM observed the results of changing the resistance on either side of a bulb, and AM was able to offer a different explanation:

> I: Yeah. So why does it get dimmer when you put the larger resistor in? What is the resistor doing?
> AM: It's holding back some of the — electricity.
> I: Okay. And then when you increase the other one, what happens?
> AM: Gets dimmer! Okay.
> I: Why is that?...
> AM: Maybe because it — I figured the current is set — (quietly)back and forth — (unhooks wires and tries the two resistors for R2 again, comparing resulting brightness of the bulb)
> I: What if instead of a resistor, that was another light bulb in that circuit? Would that make the bulb dimmer?
> AM: Yeah.
> I: So does that help you explain it?
> AM: All right. So you have the whole total over the whole thing. Obviously if I took out this resistor (R1) that would be bright, put that one in and it's dim, but this one is dim, because it has to — divide through the whole circuit — whatever power's going through it.
> I: So does it make a difference what order the elements are in?
> AM: I would think so, but maybe not? (thinks for a while) From this I'm thinking no. (AM, initial interview)

Furthermore, though AM's understanding of what resistance is didn't change, his practical understanding of what resistance does did change, as he was able to correctly predict that a bulb would dim regardless of which side of the bulb the resistance was increased.

Concepts held by these two students are summarized in Table 1.

Concepts		**AM, initial**	**AM, final**	**MJ, initial**	**MJ, final**
Current	Current is material or quasi-material	X	X	X	
	Current is energy				X
Voltage	Voltage is current	X			
	Voltage is a measure of current		X		
	Voltage is pressure or "push"			X	
	Voltage is potential energy				X
Resistance	Resistance is the holding back of current	X	X		
	Resistance is the restriction of current			X	X
	Resistance is the dissipation of energy				

Table 1: Summary of categories of knowledge held by the two case study students at the initial and final interviews .

2. **What relationship exists between a student's prior conceptual understanding of electrical circuits and the student's reasoning processes while solving problems involving circuits?**

3. **How does a student's meaningful learning change as the student grapples with a series of complex problems?**

To observe changes in student knowledge during problem solving and to observe how students used their knowledge as they reasoned their way through problems, students were observed and videorecorded during their labs. The first lab, which was not observed, consisted of assembling the base of the TekBot. Subsequent labs involved small projects in which students applied concepts learned in lecture. During the final lab sessions, students designed and assembled the circuitry for their "bump bot." Conversations between the students and their lab partners and conversations that the researcher engaged them in helped reveal the knowledge that the students were actually applying to the problems in lab: their body of meaningful knowledge. The researcher used the subject comments and actions to create a set of statements that summarized the subjects' expressed understanding of electrical concepts. The statement list was used to create a concept map for each observed lab, depicting the body of knowledge that students applied to each problem and the links students made between concepts. Concept maps were also created for the initial and exit interviews. This allowed comparisons to be made between the initial knowledge set, meaningful knowledge applied to the lab problems, and the knowledge set that emerged at the end.

AM was observed during three lab sessions. In two of the labs, AM spent a good deal of time assembling parts of the TekBot according to written instructions, and the conversations did not reveal adequate data. During the second observation, however, AM carried out a conversation with his lab partner that yielded a number of statements about the target concepts.

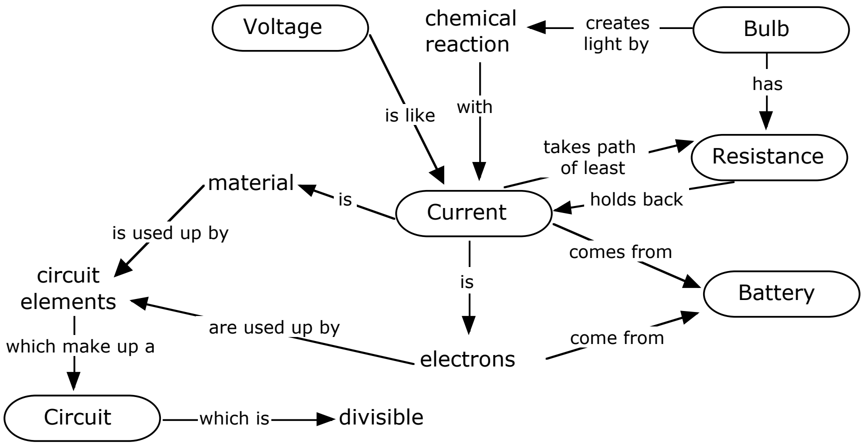


Figure 4: Concept map for AM, initial interview.

Figure 4 illustrates AM's concepts during the initial interview, and reflects the limited knowledge that AM held when he came into the class. Expressed concepts and the connections between them are fewer than what emerged in the final interview, which one would reasonably expect. As can be seen in the figure, AM's concept of voltage was not only relatively undeveloped, it was also connected to only one other concept, that of current. It is not unusual for students with low knowledge of electricity to be more familiar with current than with voltage. Most of his discussion involved describing current, which he understood to the the flow of electrons, and to be highly directional. Current he described as being "used up" by bulbs and other elements in the circuit. This may be related to the concept of current as the flow of electrons, which students often picture as material particles. In AM's view, current came from the battery where it was stored, and traveled through wires to the circuit elements, where it was used up. How it returned to the battery was not made explicit. Resistance involved holding back the material flow of current in some way, and the position of the resistor determined what effect it would have on the circuit.

Compared with the initial interview concept map, AM's map for an observation of Lab 2 (Figure 5) reveals less attention to the concepts themselves and more to the practical application of the concepts in lab. One of the main activities that AM completed in this lab was construction of two circuits, one with resistors in series and one with resistors in parallel. Students were to measure voltage across all resistors and current through them, then calculate the power dissipated. In this map, AM had altered his ideas about batteries to include batteries as a source of "power" (which AM did not distinguish from current) and as a source of voltage. By this time AM had measured the voltage of the batteries and was aware of the voltage printed on the battery label. At one point during the conversation, AM noted that if his partner wasn't getting voltage measure on a circuit that they had built, then the circuit might be incomplete; hence voltage is only detectable in complete circuits where, presumably, current is flowing.

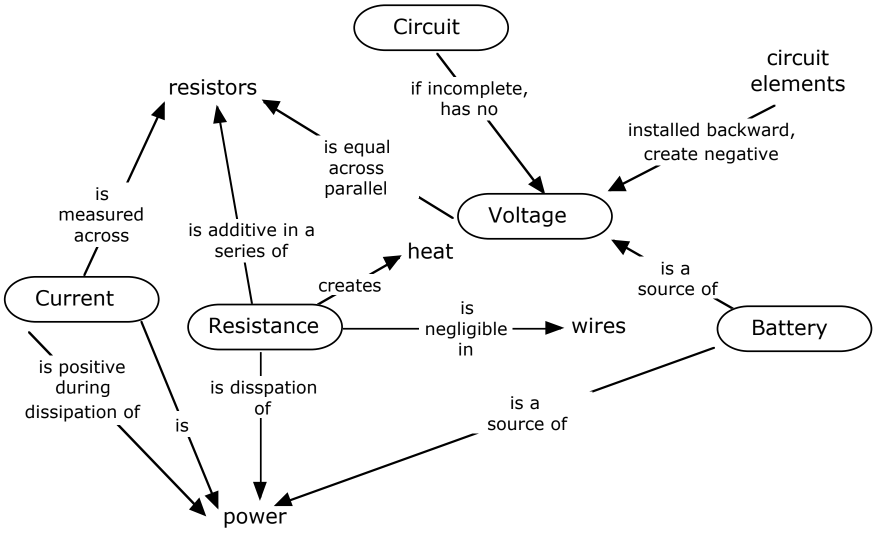


Figure 5: Concept map for AM, Lab 2

AM was aware that the polarity of certain circuit elements could affect the measure of voltage if they were installed incorrectly, and discovered that installing a diode backwards caused it to heat up to the point of smoking. Dissipation of energy was also noted in a lab activity in which AM and his partner installed the resistors into a protoboard in both parallel and series formations and measured voltage and current. AM was able to apply knowledge from lecture as he predicted that voltage should be equal across parallel resistors. AM's attempts to measure voltage and current, however, were hampered by his difficulty in distinguishing between measuring voltage across a resistor and current through a resistor. He persisted in attempting to measure current across the resistor, and required repeated instruction from the teaching assistant in lab to understand the difference

What is interesting is that little of the knowledge that AM demonstrated in the initial interview were expressed in this lab. This may have been because AM was unsure of so many concepts, and that concepts taught in lecture had more direct value to him than the concepts he initially held. Further, AM's focus was on using the concepts rather than defining them; hence most of the links between concepts relate to the observed effects of voltage, resistance, and current on the circuits he built. A few of his initial concepts, however, appear related to the connections he made between concepts in the lab. His essentially material view of electricity as the flow of electrons, and the idea that current flows in a particular direction, was reinforced by his discovery that circuit elements have polarity, and that a reversal of current causes a negative reading on a multimeter when there should be a positive reading, and vice versa.

The exit interview (Figure 6) shows more developed concepts of voltage and resistance, though the number of connections between concepts remained about the same. AM believed that voltage was a measure of current, but he knew that batteries were a source of voltage, and that voltage is related to resistance, so though he was unclear about what voltage was, he had better understandings about what it did. Given that he had spent a large part of one lab measuring the dissipation of power from resistors, it was surprising that this did not come out in the interview. He did, however, understand that a single resistor affects the entire circuit, not just those components that are "downstream."

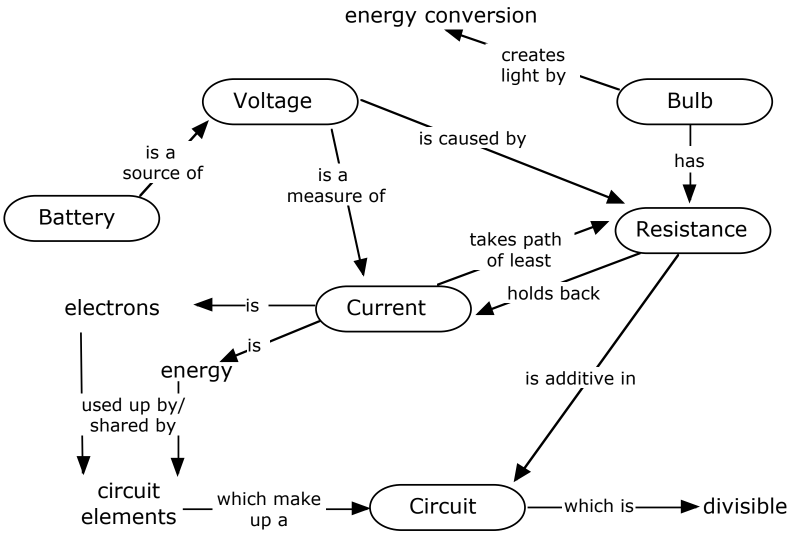


Figure 6: Concept Map for AM, exit interview

In Table 2, the body of AM's meaningful knowledge is summarized across the interviews and observations. Because the interview situations involved asking students for their understanding of particular terms, the knowledge gained in that situation encompassed both meaningful knowledge (spontaneously used) and inert knowledge (that which was recalled when asked for). Knowledge that was expressed and used in lab spontaneously is listed here under "meaningful knowledge" for the lab observation.

Knowledge: Initial interview	**Meaningful knowledge: Lab 2 observation**	**Knowledge: Final interview**
•voltage is like current •current is a material that is used up by circuit elements •current is electrons which come from the battery •resistance holds back current •current takes the path of least resistance •light in a bulb is created by a reaction of chemicals with current	**From interview** None of AM's statements in lab overtly contained knowledge from the initial interview. **From other sources** •voltage comes from the batteries •voltage is equal across parallel resistors •resistance is the dissipation of power •resistance creates heat •wires have negligible resistance •resistance is additive when resistors are in series •current is measured across resistors	•voltage is a measure of current •battery is a source of voltage •voltage is caused by resistance •bulbs have resistance •bulbs convert electrical energy into light energy •current takes the path of least resistance •current is the flow of electrons •current is energy •current is used up by or shared by circuit elements •resistance holds back current

Table 2: Summary of AM's knowledge about the target electrical concepts (circuits, voltage, current, resistance) across the term.

At the end of the term, AM expressed frustration with the class. He felt that he had been able to take schematics and build circuits from them, but understanding the underlying concepts proved difficult. AM was unsure why he needed a conceptual understanding of voltage and other concepts if he could build circuits without them. He also found the mathematics and digital logic used in class daunting.

> AM: I mean in lab there wasn't -- everything kind of made sense where everything was supposed to go. You know, I could trace where everything was flowing from and to on the board or whatnot. I was able to set up the protoboards just fine.
> I: I think that is true for a lot of people. They can follow the schematic and follow the diagrams--
> AM: But what was actually going on -- (shakes head)
> I: Yeah. It's another world. And trying to match the two becomes -- and that's part of what I'm trying to find out, what [the instructor] wants to know, too, is how much of the conceptual piece comes across from what you do in lab. Is it all coming together, or is it two different worlds?
> A: Pretty much two completely different things.

AM's score on the post-survey administered on the last day of class was 15 out of a possible 24.

MJ, like AM, entered the class with little prior knowledge and even less prior experience with electronics. MJ, however, had high math ability and demonstrated a meticulous attention to details, both of which she employed to advance rapidly in the class. She was very open and vocal about her ideas during interviews and labs, providing excellent data for concept mapping. MJ had not taken ECE 111, the introductory course taught in the fall, because an advisor had steered her into a different class. Highly aware that she was behind her peers, MJ obtained the materials for constructing a circuit board that had been a lab task in ECE 111 and assembled it herself at home and during lab.

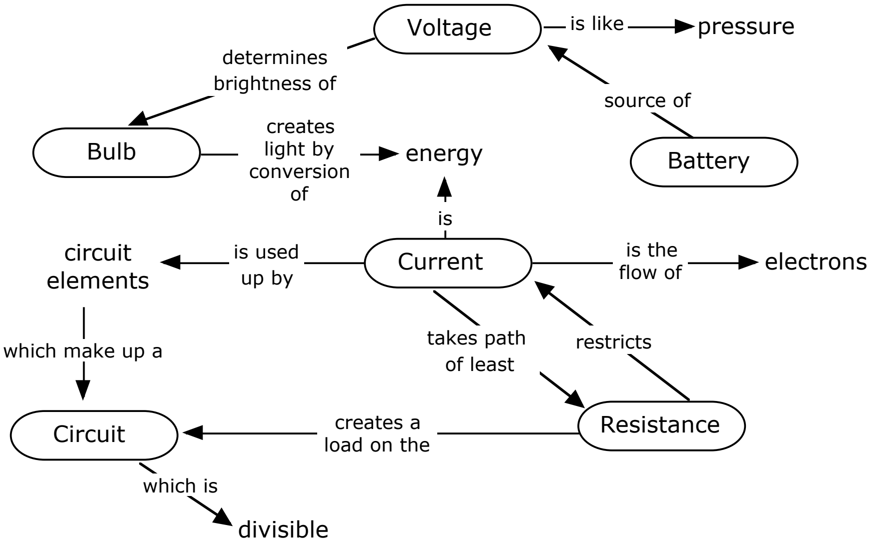


Figure 7: Concept map for MJ, initial interview

A concept map for MJ's initial interview (Figure 7) shows some initial development of concepts, as well as some alternative conceptions. In this interview, MJ was unsure of exactly what voltage was. She had learned in class that it was something like pressure. She noted that voltage affected bulb brightness, and that it was supplied by the battery. She had not yet made a connection between voltage and current, which was not unusual for other students entering the class. Hence her map shows a cluster of concepts around voltage and another around current, with little that links the two.

Like many students, MJ initially expected current to be "used up" by circuit elements, such that the first bulb in a series would be brighter than a second. By the time she reached the interview, however, she had assimilated some of the lecture material and was beginning to think in terms of voltage around the bulbs. She thought of current as something that flowed directionally, a concept that remained strong with her throughout the term and that seemed to contribute to her puzzlement over the apparent conflict between current flow and electron flow. So long as she thought of both current and electrons in quasi-material terms, it did not seem logical to her that the two should flow in opposite directions.

MJ was observed during four labs, three of which yielded sufficient data to construct concept maps. Her map for Lab 2 is presented here (Figure 8) for comparison with AM's concept map for the same lab.

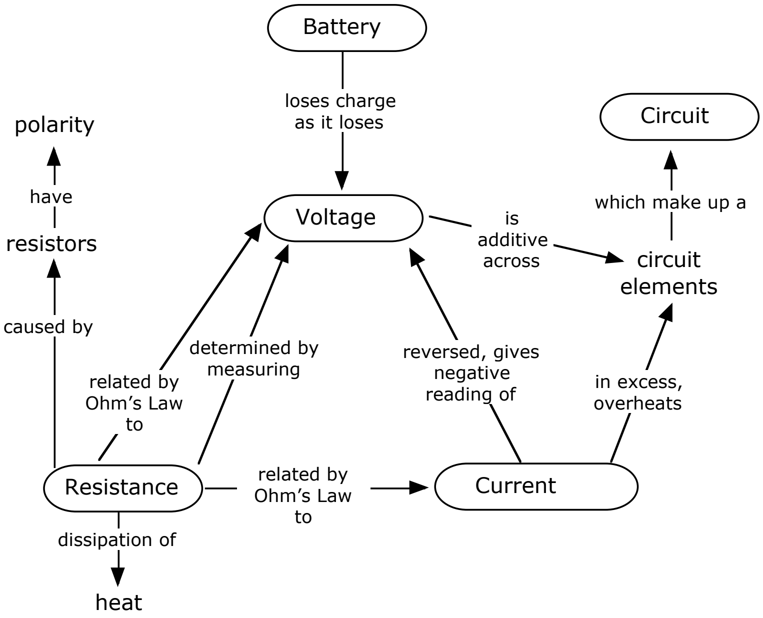


Figure 8: Concept map for MJ, Lab 2

Because the lab involved touching the resistors to see if they were hot or not, MJ expressed strong awareness of resistance as involving the dissipation of heat. She knew that too much current could cause something to overheat, again expressing the strong awareness of the cautions delivered in lecture about "smoking" their resistors. MJ approached much of the lab mathematically. She was adept at using Ohm's law to calculate resistance, voltage, and current using measurements taken in class. The batteries she discussed very little except to mention that the voltage decreases with the charge. Like other subjects, her discussions around these concepts were more situational than theoretical: less about what voltage and current were than what they were doing at the moment. Nevertheless her expectations about the basic concepts did in some cases influence her approach to the activities. For example, her concepts of directional current flow influenced her to always check that she was installing resistors and other components in the right direction.

At the final interview, MJ's knowledge of electrical concepts had developed, as had the number of connections she made between concepts (Figure 9).

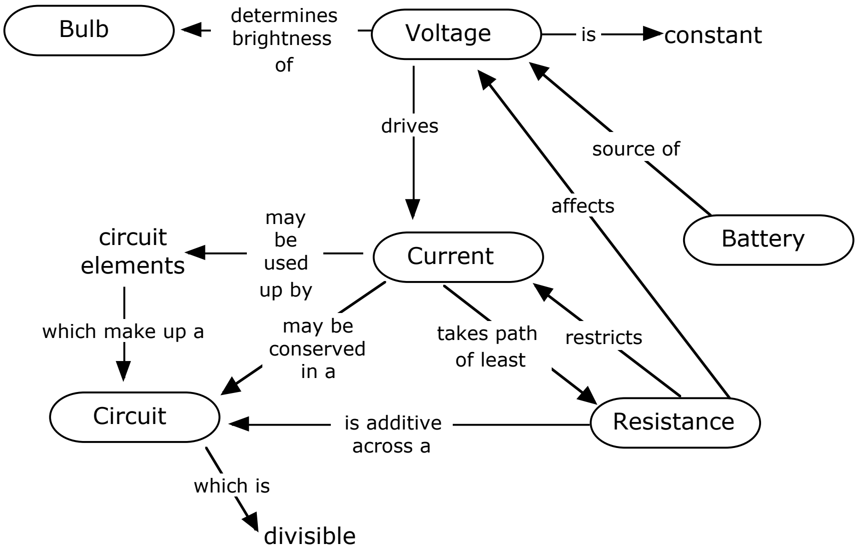


Figure 9: Concept map of MJ, exit interview

Her concept of voltage had moved from voltage as pressure to voltage as that which drives current, a slight but important difference in that the connection between voltage and current was more clear. She also saw a clear relationship between resistance and voltage, recognizing that higher resistance was associated with higher voltage. MJ still had strong expectations about the directional nature of current, and had not quite let go of an image of current as something quasi-material that is used up by the elements in a circuit, as seen by her predictions that the first bulb in a series should be dimmer than the second, though she stated explicitly that both current and voltage were conserved in a circuit.

Table 3 summarizes MJ's changing knowledge and meaningful knowledge across the term. This table includes all three observations that yielded sufficient data.

MJ expressed much higher confidence near the end of the term than AM did about her performance in class and in lab, though her confidence was always somewhat tentative. MJ knew she began the class behind her peers in knowledge and strove to bring her knowledge up to what she considered the necessary level. During lab she frequently asked the teaching assistants for help or for confirmation of her ideas, and often would have the TAs check her circuits or her diagrams of her planned circuits before proceeding. In the first labs, she often asked the TAs about the functions of the various parts of her TekBot. Because of her high math ability, she was less daunted than others by the mathematics and logic presented in class. Her score on the post-survey presented on the last day of class was 16 out of a possible 24.

Knowledge: Initial interview	Meaningful knowledge: Observation 1	Meaningful knowledge: Observation 2	Meaningful knowledge: Observation 3	Knowledge: Final interview
•voltage is like pressure. •voltage affects bulb brightness. •battery supplies voltage •bulb converts electrical energy into light energy. •current is energy. •current is the flow of electrons. •current takes the path of least resistance. •current is used up by circuit elements. •resistance restricts the flow of current. •resistance creates load on the circuit.	**From interview** •voltage is pressure. •battery supplies voltage **From other sources** •can be divided across resistors. •voltage drives current. •circuit elements have polarity. •current in the wrong direction can damage circuit elements. •excess current melts fuses. •fuses have resistance.	**•From prior lab and interview** •battery supplies voltage. **From other sources** •battery loses charge as it loses voltage. •voltage is additive across resistors in series. •negative current produces negative voltage reading. •resistance, current, and voltage are related by Ohm's law. •resistance is dissipation of heat. •resistors have polarity.	**From prior labs and interview** •voltage is additive across resistors in series. •resistance restricts the flow of current. **From other sources** •voltage drives current. •negative voltage causes negative current. •current changes linearly with voltage. •shorts in circuit affect voltage and current.	•voltage is constant in a circuit. •battery is the source of voltage. •voltage affects bulb brightness. •voltage drives current. •current may be used up or conserved in a circuit. •resistance restricts current. •resistance is additive in a series circuit. •resistance affects voltage.

Table 3: Summary of MJ's knowledge about the target electrical concepts (circuits, voltage, current, resistance) across the term.

A Tentatively Revised Model

As Whitehead (1929) described, these two students entered the class with a body of prior knowledge and continued to acquire knowledge during the lecture portion of the course. Some of that knowledge expressed initially, and some of the knowledge that was delivered in the lecture, emerged in discussions during lab as the students worked to solve the problems presented. In MJ's case the researcher was able to see what knowledge became meaningful from one lab to the next.

However, bodies of meaningful and inert knowledge do not remain static. Both students were learning new knowledge in lecture, and their knowledge changed during lab as they worked through problems and observed the effects of voltage, current, and resistance on various circuits. What knowledge emerged as meaningful changed as the context of each lab changed. Meaningful knowledge appeared to be highly situational, and tied not only to the problems presented in the lab, but to the students' interpretation of those problems.

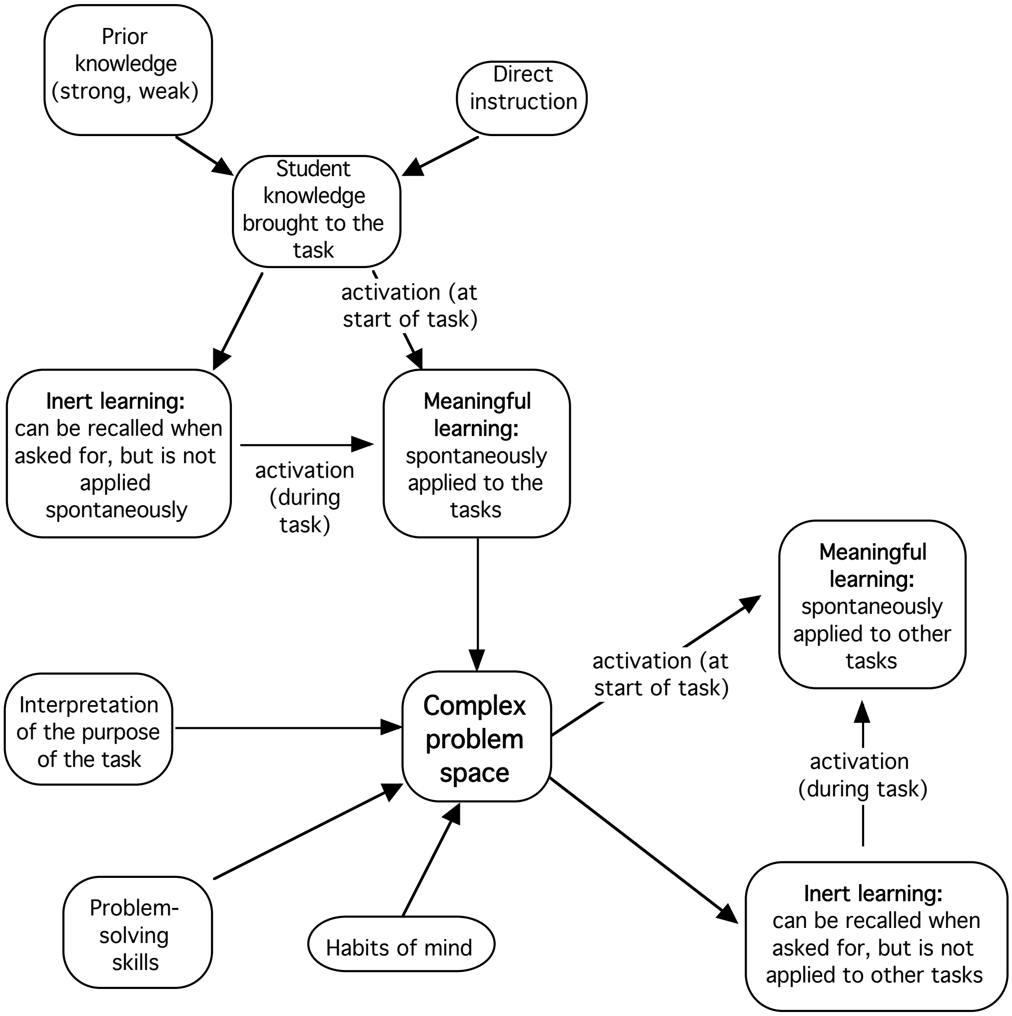


Figure 10: Revised model of task-based learning

What is shown tentatively in the revised model in Figure 10 is an area that needs more work: the interface between meaningful and inert knowledge. How is inert knowledge activated and made meaningful as the student begins a task? How is further inert knowledge activated and made meaningful during the task, as a student suddenly recalls a key piece of information that he or she had not considered before? Why is knowledge that is meaningful in one setting left inert in a different yet similar setting? The considerable body of literature on transfer of knowledge will no doubt shed some light on this, yet it would be useful to consider this question in the context of task-based learning where students are presented with a series of different yet related tasks. It is probable that the students' interpretation of the purpose of the task enters into the activation process as the student decides, "What is to be done here, and what do I need to know in order to do it?"

Habits of mind emerged as students revealed their attitudes toward the course and approaches to learning. Both AM and MJ entered the course with little prior knowledge, but relatively high math ability. MJ was about a year ahead of AM in her math coursework, but AM had more prior experience with electricity and electronics. Thus both appeared to be on equal footing as they began the course. Both spent the majority of their lab time on-task, working steadily on their lab assignments. However, conversations revealed some striking differences. MJ's conversations were largely around the lab topics. She tended to work with a lab partner, and both she and her partner worked together to understand the concepts in lab and to apply concepts learned in class to lab. MJ frequently asked the teaching assistants for help or for confirmation of her ideas. AM's conversations with his usual lab partner were frequently about topics other than lab, even while working their way through the lab activities. AM and his partner worked together when the activities required them to, but separately when they did not. While AM asked the TAs for help, he did so less frequently than MJ. Talk about the class that went on between AM and his partner was frequently negative, and AM appeared discouraged by the rigor of the course and his performance on exams. The self-perceived success of these two students may have been related to their differing levels of math, but a large part may be attributable to their attitudes toward the course and the student skills demonstrated during the course. These factors were not measured directly during the course of the research, so conclusions around this must remain tentative, but it appears to be an important factor to consider when planning task-based learning and evaluating its success.

Literature cited

Albanese, M.A. & Mitchell, S. (1993) Problem-based learning: a review of literature on its outcomes and implementation issues. Academic medicine, 68(1), 52-81.

Anderson, J.R. (1987). Skill acquisition: Compliation of weak-method problem solutions. Psychological Review, 94,192-210.

Bledsoe, K.E. (2007) How Do Engineering Students Develop and Reason With Concepts of Electricity Within a Project-Based Course? Unpublished dissertation to be submitted to the graduate faculty of Oregon State University.

Bransford, J.D., Goldman, S.R., Hasselbring, T.S., Pellegrino, J.W., Williams, S.M., & Vye, N. (1993). The Jasper Series: theoretical foundations and data on problem solving and transfer. In: Penner, L.A., Batsche, G.M., Knoff, H.W., & Nelson, D.L., eds. The challenge in mathematics and science education: psychology's response. Washington, D.C.: American Psychological Association.

Breton, G. (1999). Some empirical evidence on the superiority of the problem-based learning (PBL) method. Accounting Education, 8(1), 1-12.

Chi, M.T.H., Bassok, M., Lewis, M.W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. Cognitive Science, 13, 145-182.

Chi, M.T.H. (1992). Conceptual change within and across ontological categories: Examples from learning and discovery in science. In Giere, R.N., ed. Cognitive Models of Science: Minnesota studies in the philosophy of science (pp. 129 - 186). Minneapolis: University of Minnesota Press.

Craik, K. (1943). The Nature of Explanation. Cambridge, MA: Cambridge University Press.

diSessa, A. A. (1982). Unlearning Aristotelian physics: A study of knowledge-based learning. Cognitive Science, 6, 37-75.

Ebenezer, J.V., & Fraser, D.M. (2001). First year chemical engineering students' conceptions of energy in solution processes: Phenomenographic categories for common knowledge construction. Science Education, 85, 509-535.

Enarson, C., & Cariaga-Lo, L. (2001). Influence of curriculum type on student performance in the United States Medical Licensing Examination Step 1 and Step 2 exams: Problem-based learning vs. lecture-based curriculum. Medical Education, 35,1050-1055.

Hmelo, C.E. (1998) Problem-based learning: Effects on the early acquisition of cognitive skill in medicine. The Journal of the Learning Sciences, 7, 173-208.

Mazur, E. (1997). Peer Instruction: A User's Manual. Upper Saddle River, N.J.: Prentice Hall.

McDermott, L.C. & van Zee, E.H. (1985). Identifying and addressing student difficulties with electric circuits. In Walters, R.D. & Rhöneck, C. (eds), Aspects of Understanding electricity: Proceedings of an International Workshop. Ludwigsburg: Institut für der Naturwissenschaften and der Universität Kiel.

Nersessian, N.J. (1992). How do scientists think? Capturing the dynamics of conceptual change in science. In Giere, R. (ed.), Cognitive Models of Science, Minnesota Studies in the Philosophy of Science, 15 (pp. 3-44). Minneapolis: University of Minnesota Press.

Nersessian, N.J. (1998). Model-based reasoning in conceptual change. In Magnani, L. & Nersessian (ed.), N.J. Model-Based Reasoning in Scientific Discovery (pp. 5-22). New York: Kluwer Academic.

Osborne, R., & Freyberg, P. (1985). Learning in science: the implications of children's science. Aukland and London: Heinemann.

Saunders, K., McIntosh, J., McPherson, J., & Engel, C.E. (1990). A comparison between University of Newcastle and University of Sydney final-year students: Knowledge and competence. In Noonan, Z.M., Schmidt, H.G., & Ezzat, E.S. (eds), Innovation in medical education: An evalutation of its present status. New York: Springer Publishing Company.

Shipstone, D (1985). Electricity in simple circuits. In Driver, R., Guesne, E., & Tiberghien, A. (eds), Children's Ideas in Science, Miltone Keynes: Open University Press, pp 33-51.

Vandierendonck, A. & de Vooght, G. (1996). Evidence for mental-model-based reasoning: A comparison of reasoning with time and space concepts. Thinking and Reasoning, 2(4), 249-272.

Vernon, D.T.A. & Blake, R.L. (1993) Does problem-based learning work? A meta-analysis of evaluative research. Academic Medicine 68(7)550-563.

Whitehead, A.N. (1929). The aims of education & other essays. New York: MacMillan.