ROLE-PLAYING IN A MODELING-BASED UNIT ON ELECTRICITY FOR PRESERVICE MIDDLE SCHOOL SCIENCE TEACHERS

by

RUTCHELLE BATAN ENRIQUEZ

(Under the Direction of Ji Shen)

ABSTRACT

This study investigates how middle school preservice teachers transform different models including role-playing to reason about current electricity. A design experiment was conducted to explore the affordances and constraints of a learning sequence – in this case, a unit on current electricity that employs multiple forms of models such as computer simulations and varied analogies. Data were collected from videotaping, class observations, and student artifacts such as homework, activity worksheets, and quizzes. It was found that students demonstrated varied interpretations of a given analogy of electric current in a role-playing activity, that role-playing may be used as a diagnostic assessment, that students use appropriate props as part of their role-play, that students have the potential to develop new analogies from role-playing, and that students use multiple analogies to explain current electricity.

INDEX WORDS: Role-playing, Models, Analogies, Electric circuits, Modeling-based instruction, Design experiment
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Purpose of the Study

Students and adults have alternative conceptions in science (Driver & Erickson, 1983; Stocklmayer & Treagust, 1996; Wandersee, Mintzes, & Novak, 1994). Modeling-based instruction has shown effectiveness in helping learners change their alternative conceptions (Pallant & Tinker, 2004; Wells, Hestenes, & Swackhammer, 1995; White, 1993). One form of building scientific models in the classroom is the “human-model approach” (Shen & Confrey, 2007), or “analogy role-playing” (McSharry & Jones, 2000). Analogy role-playing in a science learning activity, or simply role-playing in this thesis, means students acting out the roles of objects or elements in a scientific inquiry to model a scientific phenomenon, process, or event, as opposed to actors and actresses taking adopted roles of people, animals, or objects in settings such as a theater (Aubusson, 1997; McSharry & Jones, 2000).

The role-playing activity in the current study was based on my previous study (Enriquez, 2007) in which I developed and implemented a lesson sequence on electric circuits for high school students in a laboratory school of a state university in the Philippines. In the set of role-playing activities that I designed, the students played the roles of bulbs, voltage sources, and electrons, and benefited from the role-playing in terms of class engagement and conceptual understanding. They gained a better understanding of electricity (e.g., current is not consumed in a circuit when the bulbs light up). It is unclear to me, however, how a human-model approach can help preservice teachers in the United States to both comprehend scientific knowledge and to engage in classroom activities.
In this study, we\(^1\) designed a learning environment that encouraged the participants to use a variety of models including role-playing to comprehend concepts related to electric circuits. We investigated the ways in which the learners (college students who are preservice teachers, in this case) transformed alternative models to better understand electric circuit concepts. Specifically, we hope to contribute to the knowledge of incorporating role-playing activities in modeling-based science instruction – the main goal of this thesis.

The following questions guide this study:

1. How did the middle school preservice teachers transform different models including role-playing to reason about current electricity?

2. What are the affordances and constraints of the role-playing activities in helping preservice teachers comprehend current electricity?

\(^1\) “We” in this paper refers to me and Dr. Ji Shen, the instructor and researcher for the course being investigated. I took the leadership role in developing and teaching the role-playing activity in the unit.
Theoretical Framework

Teaching and Learning Electricity

Students bring their prior knowledge to science classes (Osborn & Freyberg, 1985). If a student’s conception conflicts with currently accepted scientific knowledge, it is called a misconception or alternative conception (Pfundt & Duit, 1991; Van den Berg, 2002; Wandersee, Mintzes, & Novak, 1994). In learning about electricity, for example, the list of alternative conceptions is voluminous and cuts across educational systems (Osborne, 1983; Shen, Gibbons, Wiegers, & McMahon, 2007; Shepardson & Maje, 1994; Shipstone, 1988). For instance, students may think that current is decreased after passing through an electric component in a closed circuit because the current is consumed by the electric component (Osborne, 1983; Osborn & Freyberg, 1985; Shipstone, 1988).

Learning electricity is challenging because the physics concepts involved in electricity are highly abstract and complex (Mulhall, McKittrick, & Gunstone, 2001; Thacker, Ganiel, & Boys, 1999). Even if this topic is introduced to students several times in the course of their studies (from elementary to secondary to tertiary), many students are still incapable of qualitatively analyzing simple circuits (Cohen, Eylon, & Ganiel, 1983; McDermott & Shaffer, 1992). Furthermore, findings revealed that voltage, or potential difference, is one of the most difficult concepts in basic electricity since it is not connected with students’ concrete experience (Duit & Rhoneck, 1998). In addition, electric current and energy are also cited as difficult concepts because students need to make sense of the concepts with the operations on other
abstract concepts such as charge, force per unit charge, and potential energy (Van den Berg & Grosheide, 1997).

Modeling-based Instruction

Models and modeling in scientific research and science education have been extensively studied, well documented, and recently considered as integral and standard parts of scientific practice and scientific literacy (Gobert & Buckley, 2000; Nersessian, 2008; National Research Council [NRC], 1996). In science education, “models have been considered a means for a more authentic education, facilitating a scientific way to describe, explain, and predict the behavior of the world and acquire knowledge” (Koponen, 2007, p. 766).

In physics education in particular, there has been much research that looked into designed physics instruction that gives students the training to develop, evaluate, and apply models in concrete situations (e.g., Hestenes, 1987; Wells, Hestenes, & Swackhammer, 1995; White, 1993). According to Etkina, Warren, and Gentile (2005, p.15), physicists may share the following common characteristics of a model:

• A model is a simplified version of an object or process under study. This means that a person creating a model decides what features to neglect. To make the model consistent and coherent with accepted theories and observations, he or she must have a set of rules to guide the future revision of the model in case new features are recognized.

• A model can be descriptive or explanatory such that the target concept is related to some familiar objects or processes, as used in analogies.
A model needs to have predictive power, and the predictive power of a model has limitations. Thus, a model can to be modified to have better predictive power than its earlier versions.

Some physics educators have established comprehensive frameworks of modeling-based instruction. For instance, addressing the problem that college students do not learn physics well, Hestenes (1987) proposed a modeling-based approach in physics education. He defined a model as “a surrogate object, a conceptual representation of a real thing” (p.4) and emphasized that a model in physics is ultimately mathematical. He identified four components of a model, namely: “(1) a set of names for the objects and agents that interact with the mathematical model, (2) a set of descriptors representing properties of the object, (3) equations of the model, and (4) an interpretation” (p. 4). In the case of a lighted bulb in a circuit, the names of a specific mathematical model that will be mentioned are the words “voltage,” “current,” and “resistance” which are given meanings or are described with a set of descriptors such as electrical force, flow of charges, and opposition to flow, respectively. The equation is Ohm’s Law, current is equal to voltage divided by resistance (I=V/R); and the interpretation is the statement of the relationship of the three variables (e.g. if V is made constant, resistance and current are inversely proportional, meaning current will increase if resistance is decreased). An example of teaching through a mathematical model is introducing Ohm’s Law by writing the words or names of the variables and/or their symbols (e.g. V for voltage, I for current, and R for resistance) that comprise it; explain what they are; show that V=IR and how to manipulate the equation; and solve problems that require one variable when two others are given. Clearly, the model as defined in Hestenes’ paper is quantitative.
Hestenes’ definition is indeed a small part of a broader definition of model that is explained by model-based reasoning. Many scholars argue that a model is not necessarily quantitative, but could be diagrammatical, physical, or of other forms (Suppe, 1977; Koponen, 2007). For instance, Nersessian (2008, p.63) characterized a model as “a representation of a system with interactive parts with representations of those interactions” and this definition is consistent with the definition in the National Science Education Standards [NSES] (NRC, 1996). She reported that the NSES “emphasizes how models can take many forms, including physical objects, plans, mental constructs, mathematical equations and computer simulations and emphasize their explanatory power” (p. 64). She further explained that in the illustration of the works of Faraday (using visual representation or model, he reasoned the existence of various forces of nature such as waving, bending, stretching, and vibrating of the lines) and Maxwell (using a model, he derived mathematical equations to represent causal relationships of motion of particles that caused motion of vertices and vice versa), “model-based reasoning makes use of a visual representation of an imagined physical model – conceived as animated – to derive mathematical results, make theoretical hypotheses, and make experimental predictions” (p. 65).

Many scholars emphasize the strong connection between a model and an analogy. Glynn (2008, p. 114) describes analogy as a “comparison of the similarities of two concepts.” There are two components of an analogy: the analog, which is the familiar concept, and the target, which is the unfamiliar concept. An analogy can be formed between an analog and a target if they both share similar features or attributes, which means that the more features they share, the better the analogy will turn out. Mapping, a systematic comparison, verbally or visually, between the features of the analog and the target, is necessary in order to connect the analog and the target. His example for electric circuits was the water-circuit analogy (using
pipes, pump, and valve) that served as an analog to understand the electric circuit, the target. Other studies that made use of these analogies were those of Summers, Kruger, and Mant (1998), who used a bicycle pedal and a circuit sketch; Dupin and Joshua (1989), who used a toy train on circular tracks; and Van den berg and Grosheide (1997), who used microscopic creatures running around a circuit. Analogies can therefore be presented in several ways such as circuit sketches, circuit diagrams, familiar real objects (e.g. water pump, toy trains, bicycle pedal, and chain), computer simulation, and analogy role-playing (see Figure 1).

![Figure 1. Analogies of electric circuits in different forms.](image)

Similarly, Lehrer and Schauble (2000, p. 41-43) have developed a taxonomy of models based on analogical reasoning. Their forms of models are physical (e.g., popsicle sticks that represent fingers), representational (e.g., diagrams drawn to scale), syntactic (e.g., coin flip as a possible model of a bird’s preference for a type of seed), and hypothetico-deductive (e.g. collision of billiard balls to show kinetic theory of gases) models. The first two forms of models focus on obvious resemblance of the model and the world. While syntactic model uses a system that works very similar to another system in terms of internal structure or mechanism, the
hypothetical-deductive models attempt to describe the underlying mechanism of a phenomenon that are not observable. This taxonomy proposes that learners’ inscription systems can fall in any of the four forms. Thus, students’ quality of learning can be monitored and investigated in the kind of systems they use.

Dynamic computer models as a new medium may help students understand electricity. White and Frederiksen (1986) used two animated computer simulations at two different levels to represent DC electric circuits: a microscopic electron flow level as well as a macroscopic current or voltage level. They argued that when students learn from a combination of these two levels, abstract construction and deeper conceptual understanding were attained.

**Clarification of Terms in My Framework**

The term “model” is difficult to define because it is used in varied ways and contexts (Hestenes, 1987; Lehrer & Schauble, 2000; White, 1993). The term is often used interchangeably with representation. Representations, according to Kozma et al. (2000), play an important role in the scientists’ use of problem solving processes. For instance, Larkin (1983) showed that a physicist started his work using a diagram, reasoned with it, revised it, abandoned it when conflicts between the diagram and a solution could not be resolved, and derived a mathematical equation from it. Typically, when physicists communicate their ideas to others, they provide visualization or imagery to externalize their mental models to make the ideas easy to understand and to circulate for references (Latour, 1990).

In this paper, I define a “model” as a conceptual representation (as opposed to a physical representation) or a mental model that can substitute or replace something that is real, observed, and/or measured. The difference between conceptual and physical representation is that the conceptual representation is something that is in the mind of a person. If it expressed by saying
something about it, writing it, making it, or acting it out, then it becomes a physical representation. In other words, if it is perceived by any of the five senses (e.g., one can actually either hold, see, smell, operate, listen to, taste, and/or manipulate) then it is a physical representation. An example of conceptual representation is a thought or idea that electrons are like balls that go around a circuit. On the other hand, examples of physical representations of this idea are billiard balls; written words, symbols or drawings of these balls, an action of the hand that describes the balls and their movements, and an utterance that the electrons are represented by balls.

My definition of a model overlaps with the definition of Hestenes (1987) that a model is “a surrogate object, a conceptual representation of a real thing.” But I deviate from his contention that “models in Physics are mathematical models, which is to say that physical properties are represented by quantitative variables in the models” (p. 4). I submit that not all models in Physics and specifically in electricity can be exclusively and best taught using a mathematical model. While quantitative representations are useful, qualitative representations prove to be pre-requisites to better understanding of science concepts. For instance, when experts solve problems that require quantitative solutions, they start with qualitative analysis of the problem (Chi, Feltovich, & Glaser, 1983; de Kleer & Brown, 1984; Larkin et al., 1980; Zhang, Liu, & Krajcik, 2006).

As opposed to the definition of model (that a model is an analogy) by Lehrer and Schauble (2006), I argue that they cannot be used interchangeably, that they have their own unique characteristics and that they share some of these characteristics. As I have contended earlier, not all models in physics are mathematical models because there are also physical models used in physics. The two models have unique characteristics and some of these are shared with
analogies. Analogies, like mathematical models, represent real and/or observable phenomena and specifically physical properties. Thus, mathematical models, physical models, and analogies can all come together sharing several characteristics with either of the two (see Figure 2). Each of them also has specific characteristics shared by all three.

![Figure 2. My diagrammatic representation of the mathematical model, physical model, and analogy.](image)

With the characterizations and examples provided in this paper, it is hoped that readers will gain a better understanding of the use of models and modeling, specifically, role-playing as a form of modeling, in teaching and learning direct current electric circuit concepts.

*Role-Playing in Science Classrooms*

As pointed out by Doerr (1996), three modeling approaches are commonly used in instruction: (1) students use and explore existing models; (2) students compare and evaluate other available models; and (3) students build a new construct for present needs. Shen & Confrey (2007) argued that all three aspects are interlinked and that by engaging in the first two, learners are more prepared to create new models.
Role-playing in a science learning activity is a modeling process that involves all three of the above aspects. In a role-playing activity, students have to act out a model that they have learned or one that they are investigating. They may see different ways of role-playing for comparing and contrasting; and they spontaneously generate distinctive performance styles that reflect new ways of reasoning about science conceptions.

When it comes to studying the sub-micro world or molecular level (Davidowitz & Chittleborough, 2009) which is not directly observable, many researchers (Cobern, 1993; Van den Berg, 2002) have recommended that teachers employ varied social and enjoyable platforms for students to better understand science concepts. Role-playing provides opportunities for students to develop their own mental models. One example of role-playing in physics is expansion role-playing, which makes use of children representing atoms in an iron rod. The children are asked to move backward and forward as if they were vibrating. The maximum length of the “rod” is measured. The rod is “heated” by telling the children that the temperature is gradually increasing. They “vibrate” more vigorously, thus increasing the length of the “rod” (McSharry and Jones, 2009). In this role-playing analogy, the atoms that cannot be seen in real life are clearly seen by everybody in class thus understanding why there is expansion for things that are heated.

Compared to active learning, experiential learning, and child-centered learning, McSharry and Jones (2000) pointed out that the advantages of role-playing in science teaching and learning lie in the fact that students are encouraged to be both physically and intellectually involved in their lessons. Students are given the opportunities to physically express themselves in a scientific context and develop an understanding of the difficult concepts at the same time. This is empowering because the students have a feeling of ownership for their learning when they
plan their role-playing and act out these plans by themselves. Thus, role-playing may capitalize on students’ prior knowledge and learning styles.

In a role-playing activity, each individual may carry out a reasoning process called embodied imagining (e.g., Warren et al., 2001): i.e., an individual imagines him/herself within an unfamiliar physical system and makes sense out of it. Embodied imagining may help the learner switch to a different perspective (typically, from an outsider and spectator’s view to a more participatory and immersed perspective) and generate new insights. A classical example in modern physics is that Einstein, when creating the theory of relativity, imagined himself riding on a beam of light and reasoned about what happened.

The role-playing approach, incorporating embodied imagining, emphasizes the collaborative learning environment where a group of learners collectively model a scientific phenomenon or event. Students who are going to play some roles are first given an orientation about the roles. They discuss their roles in small groups and present their play in front of the class. The collaborative nature of role-playing helps students form a community of learners.
Design of the Study and the Electricity Unit

Design Experiment

This study uses design experiment as a means to explore the affordances and constraints of a particular learning sequence. A design experiment is conducted to develop theories in domain-specific learning processes. Cobb et al. (2003, p. 9) explain that the design experiments result in “greater understanding of a learning ecology – a complex interacting system involving multiple elements of different types and levels.” In order to support learning, these elements must be designed and anticipated to work together. As a design scientist, the overall purpose for conducting a design experiment for Brown (1992) is to attempt to “engineer innovative educational environments and simultaneously conduct experimental studies of those innovations” (p. 143).

Cobb et al. (2003, pp. 10-11) enumerated five crosscutting features of design experiment among a diverse range of settings that vary in both type and scope, namely:

1) the purpose is to develop a class of theories about both the process of learning and the means that are designed to support that learning;

2) highly interventionist nature of methodology;

3) create the conditions for developing theories yet must place these theories in harm’s way;

4) it has an iterative design; and

5) results have the potential for rapid pay-off.
Overview of the Electricity Unit Design

Table 1 summarizes the topics and activities of the electricity unit.

Table 1. Schedule of topics and activities of the electricity unit.

<table>
<thead>
<tr>
<th>Session</th>
<th>Date (Hour)</th>
<th>Topic</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fri. Oct. 16 (3hr)</td>
<td>Electrostatics, Insulator vs Conductor, Electrical Energy</td>
<td>Work in pairs on an online unit that involved hands-on experiments, real life problem solving, embedded assessments, and computerized models; Watch Mythbusters video.</td>
</tr>
<tr>
<td>2</td>
<td>Mon. Oct. 19 (2hr)</td>
<td>Electrical Force, Electrical Field</td>
<td>Lecture; Class Discussion</td>
</tr>
<tr>
<td>3</td>
<td>Wed. Oct. 21 (3hr)</td>
<td>Electric Current, Voltages, Resistance</td>
<td>Light up a light bulb using a battery, wire, and a light bulb; Model electric flow; Build series and parallel circuits using physical materials.</td>
</tr>
<tr>
<td>4</td>
<td>Fri. Oct. 23 (3hr)</td>
<td>Series and Parallel Connections</td>
<td>Role playing; Compare and contrast analogies; Electricity summary (PowerPoint slides).</td>
</tr>
<tr>
<td>5</td>
<td>Mon. Oct. 26 (2hr)</td>
<td>Ohm’s Law</td>
<td>Solve five basic circuits using Ohm’s Law</td>
</tr>
<tr>
<td>6</td>
<td>Wed. Oct. 28 (2hr)</td>
<td>Simple and Complex Circuits, Ideal and non-ideal Batteries</td>
<td>Review WISE; Work individually on the PhET model: DC Electricity</td>
</tr>
<tr>
<td>7</td>
<td>Fri. Nov. 2 (2hr)</td>
<td>Electricity Calculation Practice</td>
<td>Problem Practice Conceptual Physics: 456-457</td>
</tr>
<tr>
<td>8</td>
<td>Mon. Nov. 4 (1 hr)</td>
<td>Electrostatics and Electrical Circuits</td>
<td>Quiz</td>
</tr>
</tbody>
</table>

The electricity unit is comprised of lessons on static electricity, electrical force and field, electric circuits, and Ohm’s Law. Dr. Shen developed the entire unit except for the lesson on series and parallel circuits using the role-playing approach in which I was assigned to develop the lesson (see Appendix A). The unit provides opportunities for students to manipulate variables in computerized models, build physical circuits, participate in group and online discussions, and
explain their understanding using different models representing a concept (e.g., analogies). The entire unit lasts for eight sessions with an average of two hours per session (see Table 1).

In the first session of the unit students work on a Web-based Inquiry Science Environment (WISE) lesson on static electricity (Shen & Linn, 2010). In the WISE lesson students work in pairs to investigate a refueling fire accident at a gas station\(^2\). The lesson elicits students’ explanations and comprises hands-on experiments, real-life problem-solving questions, embedded assessments, online discussion, and computerized models.

The second session exposes students to the concepts of electrical force and field. Students listen to a lecture and then participate in discussions.

In the third session students are given the challenge to light up a bulb using one bulb, one battery and one wire (and with a rule that the wire may not be cut\(^3\)). Students are instructed to draw the connections that light up the bulb and come up with general rules that make the bulb lighted (see Activity 1 of Appendix B). They are then introduced to common models of electric current flow and they are to choose and explain which model is correct (see Activity 2 of Appendix B). Students then construct series and parallel circuits using several bulbs, wires, and batteries (see Activity 3 of Appendix B).

The fourth session includes three activities. The session starts with a role-playing activity, the focus of this study (details will be described in the next section). The activity involves students in small group discussions and planning on how to go about their role-playing and formally presenting their actions in front of the class. Also, they construct series and parallel circuits using several bulbs, wires, and batteries (see Activity 3 of Appendix B).


\(^3\) Based on my experience, students ask for a pair of scissors so they can cut the wire in two. Their reason for doing so is that they always see in diagrams or pictures that two wires are always connected to both sides of the bulb, thus, two pieces of wires, and not just one, will make a bulb light.
circuits, compare the brightness of the bulbs between the two circuits, explain the brightness using role-playing, present their understanding with a role-playing show, and finally discuss or critique the presentation. In the session, students also compare and contrast several analogies (e.g., water flow, car-race) including the role-playing (see Appendix C). Then Dr. Shen summarized the activities with a PowerPoint lecture and discussion.

In the fifth session, students explore Ohm’s Law through five practice problems (see Appendix D). These problems evolve from simple to relatively complex arrangements.

In the sixth session, students build and experiment with computerized models of DC circuits in a PhET simulation\(^4\). The PhET website offers a set of interactive, research-based computer models for students to learn math and science concepts. Students’ experiments in this session are guided by a worksheet developed to strengthen their understanding of series and parallel circuits (see Appendix E).

The seventh session provides the students with several review and practice activities such as calculation of voltage, current, and resistance.

In the final session students are given a quiz to demonstrate the depth of their understanding of the electricity concepts.

*The Role-Playing Activities*

In the first role-playing activity of Session 4, students were shown a sketch of electric current flow analogy (see Figure 3) using small creatures carrying backpacks of energy (Van den Berg & Grosheide, 1997). These creatures come from a battery where they get energy, they travel to the bulb to give the cracker (the bulb converts the energy into heat and light) and then they go back to the battery without the energy. This analogy illustrates that each circuit

\(^4\) http://phet.colorado.edu/simulations/sims.php?sim=Circuit_Construction_Kit_DC_Only
component has a role – the battery provides energy, the electrons that make up the wire are carriers of energy, and the bulb is the converter of energy. Also, it shows that current (in this case the flow of creatures passing through a cross section of a circuit per unit time\(^5\)) is not diminished after it passes through the bulb. Voltage is represented by the amount of cracker per creature.

Figure 3. Little creatures analogy of simple DC circuit.

Osborn & Freyberg (1985) revealed that the Consumed Model – that current is seen as “used up” by the bulb when the current passes through – is a popular explanation among students, reasoning that there would be lesser current in the wire going back to the battery. In the analogy, such misconception is addressed by showing that the creatures were not used up by the bulb thus they did not diminish in number after passing through the bulb, assuming that the creatures move at a constant speed. In order to involve students in physical and intellectual activity (McSharry & Jones, 2000), students can take on the roles of these electric circuit components and perform the human-model approach in front of the class. After showing the

\(^5\) It is important to note that the speed of the creatures determine the amount of current. If resistance is kept constant in a circuit and voltage is increased (e.g., the number of batteries is increased), current is then increased. Meaning, the creatures must move faster around the circuit.
sketch, students were then given the challenge to act out what they see in the sketch and they were not given any instruction on how to go about it. The class was divided into four and was instructed to discuss and plan their role-playing. When everybody was ready, each group presented their role-play. After the presentations, several observations on the similarities (e.g., a table or cart served as voltage source, students running around represented electrons, the water bottles represented energy) and differences (e.g., a group of students did a wave motion of their arms instead of individual students running around) with the picture and among groups were pointed out.

In the second role-playing activity, I asked for three volunteers to serve as electron, bulb, and voltage source to act out a circuit. The purpose of this activity was to demonstrate to the whole class how a role-playing activity might be done for a one-bulb simple circuit and thus provides the foundation for more complicated circuits such as series and parallel circuits. In my study (Enriquez, 2007) with high school students, I gave all the instructions to them so they would know how to do the first role-playing for a simple circuit. I observed that they were able to figure out and reason on their own how the more complicated circuits such as series and parallel circuits worked. Since then I wanted to get more opportunities to observe how students plan by asking questions instead of directing them. Hence in this activity with the preservice teachers, I did not completely take control of the role-playing demonstration. I asked the volunteers what to do next. For example, instead of positioning them into a circuit, I asked them how they would position themselves to form into a circuit. After they demonstrated exactly what was in the sketch, I asked for an additional volunteer as the second electron to make the flow of electrons continuous and to show that current involves more than one electron (in fact, for a current of one ampere, approximately $6 \times 10^{18}$ electrons pass one point per second). We then
discussed the representations in the little creatures analogy by mapping them unto the actions in 
the role-playing (e.g. students who were running were the electrons, cracker represented the 
energy, a student standing still who was holding the box of crackers was a battery), the functions 
of each circuit component, how a circuit becomes a closed or open circuit, and why current does 
not diminish after passing through the bulb.

The students were then directed to make predictions on the brightness of two identical 
bulbs connected in series and the same bulbs connected in parallel. They had to draw their 
predictions. After 10 minutes they were instructed to get bulbs, wires, and batteries to construct 
the two circuits; observe and make comparisons in terms of brightness of the bulbs between the 
two circuits; and make comparisons with their predictions and observations.

The third role-playing activity was for students to explain their observations from the 
physical circuits and come up with a role-playing to show their explanation. This time the class 
was divided into two – Group Series and Group Parallel. When everybody was ready, they 
presented their role-playings to the class and a discussion about paths and cracker distribution 
was done in order to understand why the two bulbs in parallel were brighter than the two bulbs 
connected in series.

Participants and Course Background

The participants of this study were the undergraduate students who enrolled in an 
introductory physical science course, one among several other science content courses for the 
middle school science teacher preparation program at the University of Georgia. These 
participants were chosen because we had access to the class so we could enact the design 
experiment. All students agreed to participate in the study. There were 18 students listed in this 
class and all 18 students were present during Session 4, the role-playing session. There were 17
females and 1 male. These students had little physics preparation before taking the course, as the average of the pretest (a physics basic knowledge, multiple-choice test) was 25% correct, approximately as would be expected from random answers.

Data Collection and Analysis

Multiple sources of data were collected to triangulate our findings (Patton, 1990). Selected lessons on electric circuits including the role-playing activities were videotaped. Student artifacts from homework, class worksheets, and quizzes were also collected. The videotapes were transcribed. Dr. Shen and I watched and discussed the video clips several times together.

I used the following elements of analysis and reporting (Erickson, 1986) in this thesis:

1. assertions that describe themes which were derived through inspection of data;
2. analytical narrative vignettes to give the reader a sense of being there and provide evidence of what actually happened;
3. quotes from conversations and artifacts; and
4. interpretive commentary that aids the reader in seeing the context of the assertion.

The data were analyzed jointly by Dr. Shen and me. We looked into what students said when they planned their role-playing and if these were consistent with the role-playing that they showed to the rest of the class. We gave significant attention to the actual ways that the role-playing was done, and compared and contrasted these to my own experiences of teaching electric circuits through role-playing. These comparisons served as a springboard for a rich discussion with Dr. Shen about the possible reasons for these never-before-seen role-plays, thus they became a chosen vignette. We also pointed out themes of reasoning and action that could further be analyzed, verified, and supported by other sources of data such as worksheets and homework.
Results and Discussions

Based on observations in the classroom, reflection with Dr. Shen, and students’ comments in Session 4, the role-playing activity was successful in that all students immersed themselves in the activity by planning and carrying out their creative performances and by carrying on a discussion with their peers and with the instructor on how the role-playing activity is connected to understanding electricity concepts. Here, I select and present the results of this session that I think may promote interesting discussions on how to better design and use a role-playing activity in the future.

Diverse Interpretations in the Role-playing Task

In order to elicit students’ ideas about an analogy of current in a circuit, I gave the class a challenge during the first role-playing activity – to act out or role-play what they see in a given sketch (see Figure 3). Recall that the class was divided into four groups and they were instructed to discuss with their group mates how to act out the sketch and show their role-playing to the class. There were no guidelines on how to do the role-playing. By so doing, I provided the students the opportunity to think for themselves. As a result, the role-playing presentations of the four groups varied in many ways (see Table 2).

Three groups (Groups 1, 2, and 3) used a student as the light bulb whereas one group (Group 4) used a chair and all groups showed different kinds of a lighted bulb. For Group 1, the student playing the role of the light bulb threw her hands up while the student in Group 2 accepted the water bottle and made her two arms meet above her head. Similarly, the student in Group 3 made her two arms meet above her head all the time while all her group mates passed
by her. As for Group 4, all group members held hands to form a loop with the chair included in
the loop and then one student declared that the, “light goes on.”

Table 2. Comparison of representations of four groups.

<table>
<thead>
<tr>
<th>Circuit Components</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulb</td>
<td>They used a student as a light bulb.</td>
<td>They used a student as a light bulb.</td>
<td>They used a student as a light bulb.</td>
<td>They used a chair as a light bulb.</td>
</tr>
<tr>
<td>Voltage Source</td>
<td>Their voltage source was a table with labels of + and – terminals.</td>
<td>Their voltage source was made of two students standing back to back with labels of + and – terminals.</td>
<td>Their voltage source was a cart. The + and – terminals were not labeled but verbally noted.</td>
<td>Their voltage source was a table. The + and – terminals were not mentioned.</td>
</tr>
<tr>
<td>Wire</td>
<td>They held hands to form a loop.</td>
<td>A student was assigned as ‘cable’ and it was interesting that the cable ran around to bring water bottles to the bulb. There was no mention of electrons.</td>
<td>They did not mention a wire. They also did not hold hands. They stood around a table to form a circle.</td>
<td>The students holding hands represented the wire to form a closed loop. Seems like they showed a macroscopic arrangement of a circuit, which technically did not meet the task of acting out what was in the picture.</td>
</tr>
<tr>
<td>Energy</td>
<td>No mention of energy.</td>
<td>No mention of energy.</td>
<td>No mention of energy.</td>
<td>No mention of energy.</td>
</tr>
<tr>
<td>Current Flow</td>
<td>First student made a wave motion from her right hand, which was attached to – terminal then wave continued to the next student, then third student (acting as the bulb) raises hands.</td>
<td>A student started from – terminal and, received a water bottle then ran to bulb to give the water bottle and went back to + terminal and did the same as the first round.</td>
<td>Five students ran around a table passing by a cart and a student who played bulb.</td>
<td>Students did not move around. They held hands and made a loop making sure all components, the chair (representing bulb) and the table (representing voltage source) were in one loop, and said, “Now the light goes on.”</td>
</tr>
</tbody>
</table>
The voltage source was also acted out differently. Groups 1 and 4 used a table, Group 3 used a cart, and Group 2 used two students. Three groups indicated the electrical terminals: Group 1 labeled the positive and negative terminals of the voltage source; Group 3 verbally pointed out the positive and negative terminals; Group 2 had one student labeled with positive terminal and the other labeled negative terminal.

To represent the current flow, two groups (Groups 1 and 3) had student(s) going around a loop and one group (Group 1) made a wave motion using their linked arms representing a closed loop while another group (Group 3) held hands to show a closed loop without moving students or arms around and declared that the bulb lighted.

To represent the wire, two groups (Groups 1 and 4) held hands to form a loop and the other two groups had moving students in a loop. None of the groups mentioned energy but it is important to note that one group (Group 2) used a water bottle being carried by a moving student, who was a “cable,” for every one loop and gave it to the student-bulb.

It is also interesting to note that the groups had different teamwork styles. In Group 1, two students took a leadership role and gave their teammates instruction. In Groups 2 and 3 all students actively participated in the discussion and performance. One student in Group 3 was not actively involved compared to her teammates.

Figure 4 shows a snapshot of each group’s role-playing. The role-playing of Group 1 is one that I consider the most unusual interpretation of acting out Figure 3 for two reasons: (1) I have not seen such an interpretation before since this was my first time to elicit students’ ideas before introducing them to role-playing electric circuits, and (2) the provided sketch of Figure 3 was simple and I did not expect other ways of acting it out. Furthermore, Group 4 did not have students running around the loop. They acted out the sketch in a manner that depicts the lighting
up of a bulb in a physical battery, wire, and bulb connection. They showed a macroscopic view of the circuit and there was no atomic level view depiction. It is unclear to me how they came up with these ideas, but the diversity of role-playing in such a small class did surprise me.

Figure 4. The four groups while acting out Figure 3.

These examples showed that a role-playing task can be interpreted in various and creative ways. Specifically, in this case a static imagery of an abstract concept (Figure 3) led to several legitimate and creative performances (e.g., the wave form of current flow). This demonstrates that a role-playing activity can be very helpful in a science classroom in that it may help students construct a model (human model) and reason about abstract science concepts using their own ideas. It also gives opportunity for students to see multiple ways of constructing models from their peers.
Role-Playing as a Diagnostic Assessment

Students’ diverse interpretations of current electricity in role-playing can also be used to diagnose students’ understanding (Aubusson et al., 1997, McSharry & Jones, 2001). Here is an example. During the planning stage of the first role-playing activity, right after the sketch was given to Group 2, Florence (pseudonyms are used for students’ names in the thesis) immediately spoke about the picture.

Florence: I think your backpack is the electrons. Your backpack has something in it. You drop it off at the light bulb. And then you’re back at the other [pointing to the battery in the picture] and then you get refill.

Sarah: [nods]
Aura: [nods]
Rebecca: I can be light bulb.
Florence: You can light up [raising her two arms above her head]. We could have different objects for electrons like every time she passes around. Or we could use my water bottle that would be...[getting a small bag from the floor then gets a water bottle instead and puts it on the table]. This is gonna be great.

A closer look at the conversation of Group 2 reveals that the students had the misconception that electrons were consumed by the light bulb as they stated that they would drop “electrons” at the battery. By establishing that “the backpack is the electrons” and that “you drop if off at the light bulb” show that electrons are left with the light bulb and no more electrons go back to the battery, thus, current is consumed. This conversation explains this group’s role-playing presentation. During their presentation, Florence first introduced herself and Rebecca as the negative and positive ends, respectively, of the battery. Then she introduced Aura as the cable and Sarah introduced herself as the light bulb. Aura was given a water bottle (in this case it represents an electron) by Florence (negative terminal of the battery), ran to Sarah (light bulb) and went back to the side of Rebecca (positive terminal of the battery) and got another water bottle from Florence. In this role-play, they did show that the first electron was dropped off at the
light bulb, that the cable returned to the battery without an electron, and the cable got another electron to start a new round. The role-playing has shown the students’ conception that there is more current before entering the bulb and lesser current after the bulb. This Current Consumed Model was evidently present among these preservice teachers as in the case of children and college students in different countries (Osborn & Freyberg, 1985; Tjis & Van den Berg, 1995).

Furthermore, this group’s misconception was also reflected in an activity during the previous session. During Session 3, the whole class was tasked to choose the correct model of electric current flow from four options (see Activity 2 of Appendix 2), all four members of this group chose the Current Consumed Model. Their role-playing corroborated their misconception that current is higher before getting into the bulb and is lesser after the bulb. Rebecca explained it as, “The magnitude in the beginning current is stronger because it provides the energy to light the bulb” (Figure 5).

Figure 5. Rebecca’s explanation of why Model C, the Current Consumed Model, is correct.
Similarly, other alternative ideas were also revealed when they role-played parallel versus series circuits during the third role-playing activity (e.g., students may think that the current is a constant even when the circuit is changed). These instances showcase the great potential of using role-playing as a formative assessment to diagnose students’ conceptions.

Role-playing also offers great opportunities for the instructor to pose critical questions to help students sort out their own ideas and gain deep understanding. For example, when the students in Group 2 acted out the circuit and the “carrier” dropped the water bottle during the first role-playing activity, I could ask the students if they ought to drop the water bottle or the water in the bottle. In another example there was an instance in the role-playing demonstration (second role-playing activity) when Clarisse, who played the role of an electron, asked if she should break apart the whole cracker that she was holding. In this demonstration, Alice played the role of a light bulb, Clarisse as electron, and Tina as battery. The following dialogue shows that a teacher’s questions can make students think and reason about their ideas and suggestions.

Rutchelle: So now we’re ready. Let’s say for example, Tina is a 1.5V battery. Now, the electron will get a piece of cracker
Clarisse: [takes out 1 piece of cracker from the box]
Class: [laughter]
Rutchelle: Now what will you do next?
A student from the class: Run to the bulb.
Clarisse: Can I break it apart?
A student from the class: Just take a bite.
Clarisse: Yeah, yeah. Just take a bite [says this while walking towards Alice, then gives the cracker to Alice. Alice in turn eats a bite from the cracker]
Class: [laughter]
Clarisse: [walks forward towards Tina and makes a high five to the right hand of Tina]
Then I get another one [while getting another cracker from the box and then she goes to Alice].
Alice: [takes another bite of the first cracker and receives the second cracker]
Clarisse: [goes back to voltage source]
Class: [laughter]
Rutchelle: Okay. Great. Let’s stop there. Pause. Like in a DVD, pause. So, what did you notice happening here?
Class: [silence]
Rutchelle: Any thoughts?
Student in the class: The battery provides energy to the electron.
Rutchelle: The battery provides energy. The electron….
Student in the class: Carrier of energy.
Rutchelle: Carrier of energy. Was the electron consumed by the bulb?
Class: No
Rutchelle: No. It went back. Did it go back to the voltage source?
Class: Yes.
Rutchelle: But this time without…
Class: Without the cracker.
Rutchelle: Without the cracker. Now wait a minute. I heard, I heard you saying that the electron should get a bite of the cracker or energy.
Class: The bulb.
Rutchelle: Should the electron do that?
Class: No.

Clarisse’s classmates had a suggestion after she asked whether she had to break the cracker apart. The class’ laughter before she asked the question might have prompted her to ask this question because it seemed that the cracker was big for Alice to chew so she must have thought about making the cracker more manageable by breaking it. When a student suggested, “Just take a bite,” Clarisse agreed to this suggestion but did not take a bite from the cracker. She proceeded to give the cracker to Alice who took a bite from the cracker. This opened an opportunity for me to question the suggestion and ask if the electron should do that. The students said that the suggestion was directed to the bulb (Alice), who indeed just took bites from the big cracker. Had it been directed to Clarisse, I could ask other questions to make students think deeply about electric circuits. A few questions could be: in this scenario, why should an electron consume part of the energy; would it have effects on the brightness of the bulb; and would this partial consumption hold as a general rule when electric circuits are expanded to having more loads or connected in series and in parallel.
Props Used in Role-Playing

In a typical science classroom, students are provided with many learning materials (e.g., hands-on materials, lab equipment, computer simulations). In a role-playing activity, students may select their own materials as the props for the play (whatever they see as convenient and accessible in the classroom) and interpret these materials in their own ways (e.g., water bottle, cart, table as electron or battery). Students’ use of props can raise interesting teachable moments.

For example, during the role-playing of a series circuit and a parallel circuit (third role-playing activity), Group Series used crackers as energy while Group Parallel used markers as energy. The reason for the difference in props was that Group Series had to show that the energy was divided equally among the two identical bulbs. In a physical circuit, the brightness of the two bulbs would be half as much compared to only one bulb in a circuit. On the other hand, the markers were more convenient to use in the parallel role-playing because each electron had to bring one whole marker, went around one path only, and there was no need to show that the energy was divided. In a physical circuit, the brightness of the two bulbs is the same and they are as bright as one bulb in a circuit. If Group Series used markers in their role-playing, they would not be able to show that the energy had to be divided among the two bulbs, which would indicate that they are dimmer than the bulbs in parallel. If they used two markers in order to give one to the first bulb and another to the second bulb, the two bulbs would then be as bright as the two bulbs in parallel, which is not the case. Thus, the use of these props provides opportunities for examining what fits into the role-playing and the science concept.

Still another example of the importance of props is shown in the following scenario. During the role-playing demonstration (video transcription is provided in the preceding section), the use of a big cracker (instead of a small one) brought about a teachable moment. Alice (bulb)
could not eat up the entire cracker because it was big, which may make the rest of the audience think that the bulb only lights up at a short period of time (i.e., one bite and one chew is equal to one blink of the light bulb), which is not the case at the macroscopic level. This notion may thus be avoided by providing a second part of the demonstration – adding another student into the circuit to show that there are many electrons (not just one) doing the same thing again and again thus making the lighting up of the bulb continuous and not on and off.

After this demonstration, the partial eating of the cracker made me ask whether I had to maintain the big cracker or change it with a small cracker as prop. It is necessary in the role-playing that the student-bulb shows that it ate up all the energy, which equates to it converting the electrical energy to heat and light. However, using a small cracker does offer the opportunity to naturally ask the students if the “light bulb” needs to eat the entire cracker. Furthermore, the big cracker can be extended to series and parallel circuits where it can be easy to divide it up into portions.

In brief, instructional materials play a big role in setting up the conditions of modeling (Shen, 2010). In role-playing, since students may pick up their own props, it provides many opportunities to question the use of these materials and how the alteration of these materials may imply in the scientific modeling.

Extending the Role-Playing to Explain a New Observation

Students bring everyday experiences into the classroom and they use these to reason their understanding of a new knowledge or observation (Bransford et al., 2000; Clement, 1982). This was evident in the third role-playing activity in the unit, in which students were asked to plan a role-playing that would demonstrate and compare series and parallel circuits. Even though the class was not instructed to do so, two students of Group 1 experimented with a hybrid
arrangement, i.e., combination of a series and parallel circuits with one bulb (A) in series with two bulbs (B & C) in parallel (Figure 6 shows what the students drew on their worksheet). They used the little creatures analogy to explain the relative brightness of each light bulb. The following excerpt shows that Jessica and Victoria applied an everyday experience of crumbs into the cracker analogy.

Jessica: Think of it as the little things. Um, think of it as the people having crackers. So it’s pulling positive, they are arriving out right here, they get here. They all give their cracker to this light bulb. Okay? But a few of them

Victoria: have like crumbs

Jessica: [nods] have crumbs. So a few of them still have crumbs, they split off, and they go split, split exactly. Half go here and half go here and they give their crumbs to these light bulbs.

They explained that a bulb in the mainstream of a circuit gets the major chunk of the energy and those that are not in the mainstream get “the crumbs,” or very small portion of the energy, thus they are dimmer than the bulb in the mainstream. Furthermore, they indicated that the two bulbs in parallel would be equal in brightness because the crumbs would be split between the two of them equally.

I have never encountered the idea of crumbs in the whole time that I taught role-playing to high school and college students. It is interesting to note that they used the concept of crumbs,
which is a real-life experience (we have our experiences with crumbs from crackers, bread, cookies) and a natural extension of the role-playing they did, to explain the dimmer Bulbs B & C.

It is important to note, however, that when we talk about crumbs, our connotation of it is very small pieces and that is does not have a near approximation to a fixed quantity (e.g. one eight, one fourth, one half). In a physical circuit connected in series-parallel as shown in Figure 6, the current through Bulb A is equal to the total current of Bulbs B and C and that that the voltage drop across Bulb A is twice as much as Bulbs B and C. This is because Bulb A is the only single load in a single connection. But after this connection comes two connections and they are the two bulbs (B and C) in parallel, which now provides two paths for the electrons to go through. Thus, this idea of crumbs is not a near and accurate description of the amount of current that goes through the bulbs but that the equal splitting of the crumbs clearly shows why Bulbs B and C would have the same brightness.

This series-parallel connection is a more complicated circuit to handle. This is another opportunity for students to reflect on the kind of role-playing they have to develop in order to work through the abstract concept of current (Aubusson et al., 1997). In more advanced lessons, students may be given two or more combinations of series-parallel circuits. Students can either be made to predict the amount of current through the bulbs using role-playing or shown the circuit first and then do the role-playing. These instances support elaboration, which is necessary for understanding combination circuits that also need visualization.

Using Multiple Models to Explain Electricity

As recommended by Shen and Confrey (2007), students must be given opportunities to work on different forms of models as they afford varied forms of constructing that could lead to
“a higher level of comprehension and self-awareness of their constructs” (p. 964). These opportunities were provided in the unit and one of them was exposing the students to varied analogies such as the highway traffic analogy, which was introduced prior to this session (Session 3). The students reflected this analogy in both their reasoning during the planning stage of role-playing in the first role-playing activity and also in their homework. It was therefore evident that students may use different models or analogies to explain electricity, especially those that they have encountered already (Driver et al., 1994).

Students may also bring their own analogies (e.g., the crumb analogy). In the following exchange, Jessica, who previously created the crumbs analogy during the third role-playing activity, used the traffic jam to explain a different circuit. Meaning, students use analogies in different contexts. As to which contexts, I do not know yet. I infer that because “every analogy breaks down somewhere” (Treagust et al., 1998, p. 86), some analogies are preferred to other available analogies because they are closer to a student’s personal experience and prior knowledge (Duit, 1991). This conjecture strengthens my argument that by providing students the opportunity to act out their understanding about electric circuits, they not only own their reasoning but also their actions thus creating a personal experience with electric circuits, which could be used to construct reasoning for more complicated circuits.

Dr. Shen: Could you use the same explanation to explain when you have two light bulbs here and one light bulb [unintelligible]
Jessica: Well, I kinda have to think of it as like [unintelligible] Yeah, like she’s saying, you talked about traffic jam last time. They get to [unintelligible] working around. This one has one construction site, this one has two construction sites and so most of them go that way and some of them go that way. [unintelligible]. Just different ideas [unintelligible]
Indeed, the traffic jam analogy was popular among the students. When students were given a homework (see Appendix F) and asked about the brightness of the bulbs in a series-parallel connection (see Figure 7), several students used the traffic analogy to explain why two bulbs in parallel would be dimmer when connected in series with one bulb. Figure 8 shows three samples of students’ responses.

![Diagram of a series circuit with a third bulb added in parallel to an existing circuit](image)

**Figure 7.** A problem given in one homework: a series circuit was added with a third bulb C, which is in parallel with Bulb B.

However, the highway traffic analogy is somehow limited because students get to represent them only in words and picture. This analogy can be shown to the class in a role-playing. Students can act out the analogy in a class presentation at the same time articulate their understanding and get feedback on the quality of their reasoning (Brophy & Schwartz, 1998) from their peers and the teacher.

**Affordances and Constraints of Role-Playing**

Like other approaches in teaching, role-playing has its own affordances and constraints. First, by allowing students to get involved in physical activity such as walking around in a loop, which is analogous to the movement of electrons through a wire (Treagust, 1993), students are able to draw on their personal everyday experience (e.g., walking, distributing), develop and create their own mental models from available physical representations (e.g., sketch of small creatures analogy), express their understanding by acting out a scientific phenomenon (e.g.,
equal brightness of two identical bulbs in series) aside from explaining through words and pictures, and construct their own analogies (e.g., crumb analogy) from existing analogies. All these in turn form personal connections to scientific knowledge and this is a strategy that scientists use in making sense of the natural world (Resnick & Wilensky, 1998).

Figure 8. Sample responses of three students using the traffic analogy to explain the brightness of the three bulbs in Figure 6.

Second, with role-playing, learning becomes the result of students’ creativity and ingenuity (Shaffer, 1996) because role-playing provides opportunities to show alternative ways
of acting out a scientific phenomenon. When students are asked to role-play their mental model of electric current, they can come up with different ways to act out that mental model and they even add some props into their show. These actions serve as evidence of students’ existing ideas about the concept. This affordance is very much necessary to the third affordance and that is, role-playing can be used as diagnostic and/or formative assessment (Harlen, 2003). By giving students a role-playing task, be it acting an existing model or creating their own, a teacher will know students’ prior knowledge, their ways of thinking about a concept, and whether or not desired skills and ideas are being developed.

Fourth, role-playing can assist in the shifting of perspectives among multiple analogies while students compare and contrast alternative analogies that are presented in class by other groups of students. Shifting perspectives means reflecting and using one analogy and then exploring the plausibility of another proposed analogy. This way, several limitations or strengths of the analogy may be pointed out which can therefore lead to revising the analogy.

Finally, as there are several roles to be played in a role-playing activity, it is therefore a social activity that requires collaboration. Students need to discuss and plan a given analogy and how they should act it out. They may also be given the challenge to explain a science concept using an analogy and then acting it out. A group work like this requires students to ask about each other’s ideas and the plausibility of these ideas in the analogy.

Role-playing has constraints. One is that it requires some prior knowledge on both the analogy being role-played and the rules and structure of the role-playing activity. Student's knowledge of the analogy in the construction of explanations is a very important matter to consider (Stephans et al., 1999). Thus they need to be familiar with how the model works and what rules to observe. Also, prior content knowledge of the topic is equally important (e.g.,
current is a flow so there must be a show of flowing things in the analogy). Still another constraint of role-playing is that it needs instruction of acting. If a teacher shows how to role-play an analogy, this somehow sets a prevailing style for role-playing, thus limiting the possibilities of creating other ways of role-playing an analogy of a science concept. Finally, role-playing that is based on personal experience may lead to alternative conceptions (Glynn, 2008).
Conclusion and Implications for Teaching

This design study has shown that the middle school preservice teachers, given proper scaffolding, could transform different models (Shen & Confrey, 2007) including role-playing to successfully reason about current electricity.

The data shows that by allowing students to get involved in physical activities (e.g., walking around to simulate the movement of electrons), students are able to draw on their personal experiences to develop and extend explanatory models (e.g., the crumb analogy). If a teacher designs instruction in such a way that taps into the daily experiences of students, science concepts can thus become embedded as a personal experience to these students. However, teachers need to be reminded that these personal experiences may bring new alternative conceptions.

Through role-playing, students demonstrate their prior knowledge of electric circuits when they expressed their understanding (e.g., dropping water bottles at a “bulb”). This helps a teacher become aware of students’ conceptions, specifically alternative conceptions. This also provides an opportunity for the teacher to assess the development of ideas students have in a creative form. Based on students’ performances, teachers may raise key questions and create new activities (e.g., small group discussion, compare and contrast group role-playing, peer critique and evaluation) to address these conceptions accordingly.

Students also spontaneously use readily available materials in the classroom (e.g., use of markers) to serve as props that illustrate science concepts. This can generate critically teachable moments that prompt a teacher to ask questions for students to reason about why such props are
used and how they fit in the science concepts. It is also important for a teacher to prepare a variety of teaching materials for a role-playing activity.

Besides role-play analogies, students may use multiple analogies (e.g., highway traffic analogy aside from the little creatures analogy) to explain current electricity. If a teacher provides opportunities for students to explore multiple analogies, students may be able to elaborate scientific concepts in a wide range of representations and comprehend them at a higher level (Glynn, 2008; Shen & Confrey, 2007). More importantly, the teacher needs to help students realize that all these analogies need to be consistent with each other to explain the same phenomena.
**Future Research**

This study illustrated that students use multiple analogies when asked about a different arrangement of a circuit. However, we do not know how and why students know which analogy to use under this context. We also do not know in which contexts multiple models are evoked and how and why are they preferred over others. These are questions that need to be answered in future research.

If students were given the task to role-play more complicated circuits, how would they construct their reasoning and what aspects of the role-playing will they retain or revise? Also, it will be more challenging if students were to create their own role-plays, analyze them by comparing them with phenomena, and compare the role-plays with original role-plays of other students.

Furthermore, it will be interesting to see how role-playing helps in the retention of current electricity concepts after a certain period of time has elapsed and these same students are asked about the brightness of bulbs in different circuit arrangements. Finally, to investigate how students transform the role-playing experience to other physics topics such as heat and temperature (e.g., acting out molecular interactions) may be another aspect to look into.
References


Erickson, F. (1986). Qualitative methods in research on teaching. In M. C. Wittrock (Ed.), *Handbook of research on teaching* (3rd ed.) (pp. 119-161). New York: Macmillan.


APPENDIX A: LESSON PLAN ON ROLE-PLAYING ELECTRIC CIRCUITS

Role-Playing Electric Circuits
By Rutchelle B. Enriquez
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I. OBJECTIVES
1. Act out or role-play the electrons, voltage source, and bulbs in simple, series and parallel circuits and discuss their roles in the circuit.
2. Define energy, current and voltage operationally.
3. Discuss the difference of brightness of bulbs in the two types of circuits.

II. SUBJECT MATTER
A. Lesson: Role-Playing Circuits
   A.1 Parts and Functions of a Circuit
   A.2 Close and Open Circuits
   A.3 Energy, Current and Voltage

B. Key Concepts:
   • A simple circuit is composed of voltage source, load (such as light bulbs) and connecting wire(s). A switch may be added.
   • The voltage source supplies energy to the electrons.
   • The wire serves as a bridge for the electrons to carry electrical energy to the bulb.
   • The bulb converts energy to light (and heat).
   • The light bulb in the circuit does not light up when there is a missing component or when the circuit is open or there is a break in the circuit.
   • A circuit is open if it does not allow electrons to pass through. A circuit is closed if it allows electrons to pass through.
   • In a series connection circuit, current throughout is the same and voltage adds up to the battery voltage.
   • In a parallel connection circuit, the voltage across each load is the same and that current through each load add up to the total current in the circuit.

C. References:


D. **Time Frame:** 1 hour

E. **Materials:**
   light bulbs (identical and non-identical), batteries, connecting wires, crackers, prediction sheet, labels of circuit parts (‘bulb’, ‘voltage source’ and ‘electron’), placards (‘lighted’ and ‘not lighted’), picture of analogy

III. **LEARNING ACTIVITIES**

A. **Review**
   Ask the class whether the piece of paper on their table is true or false. If it is false, change the underlines word or words.
   1. A simple circuit is composed of voltage source or battery, load (such as light bulbs) and connecting wire(s). A switch may be added. *[True]*
   2. The light bulb in the circuit does light up when there is a missing component or when the circuit is open or there is a break in the circuit. *[False: does not light up]*
   3. A circuit is closed if it does not allow electrons to pass through. A circuit is closed if it allows electrons to pass through. *[False: open]*
   4. In a series circuit, loads form a single pathway for electrons to flow. In a parallel circuit, loads form branches, each of which provides a separate path for the flow of electrons. *[True]*

B. **Motivation**
   Divide the group into four and give them the picture below. Challenge the students by asking if they can act out what is shown by the picture. Give six minutes to discuss what they will do and write this plan down. Ask two groups to report and note the roles they mentioned.

C. **Lesson/Activity Proper #1**
   Ask for volunteers to role-play the roles mentioned and point out what could be missing, if there is any (the something in the backpack might have not been noticed by the students). Start the role-playing. **See ROLE-PLAY 1 below.**

**ROLE-PLAY 1: Electrons in a Circuit**

**Briefing:** Give a briefing/orientation about this activity by explaining that the role-playing will be done in order for students to perform the roles of the components in a circuit. The teacher will give instructions as to how to go about with the role-playing. Also, it is important to mention to the class at this point that both actors/role-players and audience are important in making the role-playing successful. This will only be the role-play that the teacher will give instructions. In the next role-playing activities, students themselves will plan their role-playing presentations based on the first role-play facilitated by the teacher.
Give the following instructions to role-players while addressing the class:

a. Three students are needed for the first simple role-playing. The first student will act as a voltage source or battery, the second as a bulb and the third as electron. The cracker represents energy. Electrons are the mobile particles of atoms. In metals, the outermost electrons or electrons farthest from the nucleus are held loosely so they are free to move from atom to atom, hence, they are called free electrons.

Acting:

b. First, use one electron to make the situation simple. The student acting as electron will start at negative terminal of the battery (say 1.5 V) and will get a whole cracker from the one acting as the battery. The electron will go to the student acting as the bulb and gives the cracker. While the student acting the bulb eats the cracker, he/she will raise an appropriate flashcard (“lighted” or “not lighted”). The electron will continue to move to the positive terminal of the battery without a cracker.

The role-playing can be done again, this time, without instructions coming from the teacher. Since there are many electrons in the wire, repeat the role-play with more students acting as electrons.

c. What happens if for example, there is a break (which can be before or after the bulb) in the wire? Tell the actors to show this in a role-play [Electrons will stop moving and student playing a bulb will raise “not lighted”]

Debriefing:

d. It is at this point that you debrief the role-play by discussing the following:

- The people electrons are all different from each other. The real electrons are identical.
- In reality, many electrons (6.2 X 10^{18} electrons) pass at one point. But to make the role-play simple, only one student represents one particle passing through a point.

D. Discussion #1

Ask the following questions about the role-play:

1. In the play, which one is the battery?
   [The one who gives out the crackers.]
2. What does a battery do?
   [It gives energy to the electrons.]
3. What is the job of the electrons?
   [They carry the energy to the bulb.]
4. What does the energy do to the bulb?
   [It lights up the bulb.]
5. Were the electrons consumed by the bulb?
   [No, they weren’t.]
   -What did the bulb do?
   [It used up only the energy.]
6. After delivering the energy, where did the electrons go? 
[They went back to the dry cell]
7. What happened when there was a break in the circuit? 
[The bulb didn’t light up and the electrons stopped moving.] 
-Is it an open or closed circuit? 
[It is an open circuit.] 
-When do we say that it is a closed circuit? 
[When the electrons can complete a loop and light a bulb.]
8. Can you see current being represented in the role-play? How about voltage? How about energy? 
[Current is the amount of electrons passing through a point in a conductor per unit time. These are the electrons moving. Voltage is the energy each electron has. It is an electron with carrying an amount of energy. Energy was represented by the cracker. The unit for energy is Joule. So we say, for example, for a 1.5V battery, a coulomb of charge is carrying 1.5 Joules of energy.]

E. Lesson/Activity Proper #2
Divide the class into two and each group will role-play the following:

Group 1
Role-play A: two identical bulbs in series connection
Role-play C: two non-identical bulbs (one has higher wattage than the other) in parallel connection

Group 2
Role-play B: two identical bulbs in parallel connection
Role-play D: two non-identical bulbs (one has higher wattage than the other) in series connection

Each group must first predict the brightness of the bulbs. These should be written or drawn on the prediction sheet. After predicting, they can go ahead test their prediction with the real circuits and discuss their role-play in six minutes. Presentation will be from role-plays A-D.

F. Discussion #2
Ask how the role-plays were done and how they came up with such decisions. What aspects can be identified as limitations of the role-playing.

G. Lesson /Activity Proper #3
There must be some way to prove that (1) current throughout a series connection circuit is the same and (2) voltage adds up to the battery voltage. Similarly, there must be a way to prove that for parallel connection circuit, (3) the voltage across each load is the same and that (4) current through each load add up to the total current in the circuit. Instead of the teacher supplying these information, students can explore these by giving them the opportunity to use an ammeter and voltmeter.
Show students how to use an ammeter and voltmeter in measuring current and voltage and use the same circuits in the role-plays to measure current and voltage at certain points as required in the activity.

For series circuit with identical and non-identical bulbs:

```
I

V1

V2
```

For parallel circuit with identical and non-identical bulbs:

```
I1

I

V
```

H. Discussion #3
Discuss if the above concepts 1-4 are true based on their experiment.

Note: Parts G and H above are not included in the one-hour allotment in this lesson plan. This is only to show that the experiment could fit into this part of the lesson if the teacher wishes for students to do measuring activity and after this activity, Ohm’s law may also be introduced. The following objectives and key concepts are provided if the teacher wants to do the measuring activity:

Additional Objectives:
• Describe the functions of an ammeter and voltmeter.
• Connect an ammeter and voltmeter properly in a circuit.
• Measure the current and voltage in a circuit.

Additional Key Concepts:
• An ammeter is a device used to measure current (symbolized by capital letter “I”) at a point in the circuit while a voltmeter is a device used to measure potential difference or voltage (symbolized by capital letter “V”) between two points in a circuit.
• The ammeter is connected in series with the load in the circuit.
• The voltmeter is connected in parallel with the load whose voltage you are to measure in the circuit.
• The unit of current is Ampere (symbolized by capital letter “A”) while the unit for voltage is Volt (symbolized by capital letter “V”).
I. Generalization
Ask students to make generalizations or small rules about the concepts learned from role-playing the series and parallel circuits.

IV. ASSESSMENT
1. Decide which of the following circuits is correctly assembled and will light the bulb when the switch is closed. Write the number/s only. [Answer: only Circuit Number 1 and 7]

![Circuit Diagrams]

2. What part of the simple circuit
   2.1 serves as a carrier of energy?
      [Answer: metal conductor/wire]
   2.2 converts the energy possessed by the moving electrons into light and heat?
      [Answer: bulbs]
   2.3 provides energy that moves the free electrons in a conductor? [Answer: dry cell or voltage source]

V. ASSIGNMENT
Use Creative Writing for this assignment. Let the students write paragraphs on ‘A Day in the Life of a Current Particle’. Do not limit the number of paragraphs so students’ understanding is assessed.
APPENDIX B: THREE ACTIVITIES OF THE THIRD SESSION

Activity 1: Complete Circuit

Materials: a light bulb, a piece of wire, and a battery.

Tasks:
  • Connect these components in as many ways as you can to make the bulb lit.
  • Sketch your arrangements for both
    (a) the bulb is lit, and
    (b) the bulb is not lit. (draw on the back side)
  • Summarize your general rule of how to make a light bulb lit.

Sketches of bulb being lit:

General Rule:
APPENDIX B (continued)

Activity 2: Models of Electric Flow

Materials: light bulbs, light bulb holders, wires, batteries

Tasks:

• Discuss with your classmates which of the following model you think is correct. How do you know?

We predict that …

This is because …

Figure 1. Common ideas about electric current. In Model A, only one wire is needed and the electric current flows from the battery to the bulb; In Model B, the direction of electric current is from the battery to the bulb in both wires; In Model C, the direction of the electric current is shown and the magnitude will be less in the return wire; In Model D, the direction of the electric current is shown and the current will be the same in both wires.

• Set up complete circuits to test these models by repeating the following steps (using the table in the back).
  o Choose a model to test.
  o Construct an experiment to test it.
  o Sketch your arrangements and make the connections.
  o Write down your observations and conclusions from these observations.
<table>
<thead>
<tr>
<th>Sketch of Arrangements</th>
<th>Observations</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<tr>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX B (continued)

Activity 3: Models of Series and Parallel Connections
Series Connection: electric components are connected in a series (one after another).

List all you know about series connections:

Parallel Connections: electric components are connected to the same two points of an electrical circuit.
### APPENDIX C: WORKSHEET ON COMPARING MODELS OF ELECTRIC CURRENT

<table>
<thead>
<tr>
<th></th>
<th>Water Flow Model</th>
<th>Car Race Model</th>
<th>Human Role-Play Model</th>
<th>Scientific Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Diagram</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Flowing Element</strong></td>
<td>water droplets/molecules</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Flowing Route</strong></td>
<td>complete water cycle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Energy Source and transformation</strong></td>
<td>electric pump electric $\rightarrow$ potential</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Potential Difference (V in Voltage)</strong></td>
<td>10 J to raise one kg of water a height of 1 m</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Current (I in Ampere)</strong></td>
<td>mass of water passing a check point per unit of time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Resistance (R in Ohm)</strong></td>
<td>bumps; narrowed channel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Constraints/ Relationships</strong></td>
<td>water flow (I) is proportional to height raised and inversely proportional to conditions of water channel (R)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Power=energy/time P=IV (in Watt)</strong></td>
<td>amount of energy passing a check point per unit time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Situations when the model cannot explain</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### APPENDIX D: OHM'S LAW CALCULATION PRACTICE SHEET

**Five Practice Problems**

<table>
<thead>
<tr>
<th>Case</th>
<th>Electric Diagram</th>
<th>Light Bulbs(s)</th>
<th>Resistance (Ω)</th>
<th>Current (A)</th>
<th>Voltage (V)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>![Diagram 1]</td>
<td>A</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>![Diagram 2]</td>
<td>a/b</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>![Diagram 3]</td>
<td>a/b</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>![Diagram 4]</td>
<td>a/b, b/c</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>![Diagram 5]</td>
<td>a, b/c</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX E: WORKSHEET USED WITH PHET SIMULATION

Construct Circuits Using PhET

1. Launch Circuit Construction
(1) google “phet”, click the first link, then click “Play with sims” or type in the address bar http://phet.colorado.edu/simulations/index.php
(2) Find the Icon “Circuit Construction Kit (DC Only)” , Click it
(3) Click “Download!” (You can also click “Run Now” to run it online)
(4) Click the downloaded file to open the program.

2. Build Circuits
(1) Conductor VS Insulator
   a. Build a series connection with one light bulb, one battery, and some wires.
   b. Delete one of the wires to break the circuit. Click the “Grab Bag” button on the top and select the materials listed to put in the broken circuit to see if they can complete the circuit. Record your results in the table below:

<table>
<thead>
<tr>
<th>Conductor vs Insulator</th>
<th>Conductor</th>
<th>Insulator</th>
<th>surprise you?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dollar Bill</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paper Clip</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Penny</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eraser</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pencil Lead</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dog</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(2) Series Connection
   a. Build a series connection with two light bulbs, one battery, and some wires.
   b. On the right side tool menu, select Voltmeter and Ammeter. The Voltmeter will appear in the main window; the Ammeter will appear in the component column. Drag the Ammeter from the component column into the main window.
   c. Measure the current (in amperes) and voltage (in volts) across each light bulb using the Voltmeter and the Ammeter. Record your measured data in Table 2 below.
      i. The Voltmeter has to be connected in parallel with the component you want to measure. (think why?) The red clip is the positive end and make sure you get a positive reading in this lab.
      ii. The Ammeter has to be connected in series with the component you want to measure. (think why?)
   d. Measure the voltages across each light bulb and across both of them. Measure the currents at different points: (i) between the positive end of the battery and the closer light bulb, (ii) between the two light bulbs, and (iii) between the negative end of the battery and the closer light bulb. Record your measured data in the table below.
Current, voltage, and resistance in a series connection.

<table>
<thead>
<tr>
<th>Point of current measured</th>
<th>Current (A)</th>
<th>Points of voltage measured</th>
<th>Voltage (v)</th>
<th>Resistance (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>between positive end of the battery and the closer light bulb</td>
<td></td>
<td>Across one of the light bulbs</td>
<td></td>
<td>R1=</td>
</tr>
<tr>
<td>between negative end of the battery and the closer light bulb</td>
<td></td>
<td>Across the other light bulb</td>
<td></td>
<td>R2=</td>
</tr>
<tr>
<td>between two light bulbs</td>
<td></td>
<td>Across two light bulbs combined</td>
<td></td>
<td>Rtot=</td>
</tr>
</tbody>
</table>

e. From the measurements, calculate the resistances of the light bulbs and record your results in the table above.

f. Now select the button “Show Values” on the right side tool menu (category “Visual”). Check if your results are consistent with the values shown.

g. From these measurements and calculations, summarize the general rules of a series connection as the following:

h. Change the values of the resistances of the light bulbs (right click when select the light bulb), do your general rules still hold? If not, revise your general rules so that they can explain all the observations!

i. Draw an Electric Diagram including both the Ammeter and Voltmeter in one of your setups.
(3) **Parallel Connection**

a. Build a parallel connection with two light bulbs, one battery, and some wires.

b. Measure the voltages across each light bulb. Measure the currents going through each light bulb and the main branch. Calculate the resistances. Record your data in the table below.

Current, voltage, and resistance in a parallel connection.

<table>
<thead>
<tr>
<th>Branch of circuit measured</th>
<th>Current (A)</th>
<th>Voltage (v)</th>
<th>Resistance (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>One light bulb</td>
<td></td>
<td></td>
<td>R1=</td>
</tr>
<tr>
<td>The other light bulb</td>
<td></td>
<td></td>
<td>R2=</td>
</tr>
<tr>
<td>The main branch (two light bulbs together)</td>
<td></td>
<td></td>
<td>Rtot=</td>
</tr>
</tbody>
</table>

c. From these measurements, summarize the general rules of a parallel connection as the following:

d. Change the values of the resistances of the light bulbs (right click when select the light bulb), do your general rules still hold? If not, revise your general rules so that they can explain all the observations!

e. Draw an Electric Diagram including the Ammeter and Voltmeter.
(4) Series and Parallel Combination

a. Three identical light bulbs are connected in a circuit as shown in Figure A. When you close the switch, compared with when the switch is open, the brightness of light bulb 1 will ___________, the brightness of light bulb 2 will ______________.

b. Build the circuit using the software and test your prediction. Our prediction about light bulb 1 is consistent / inconsistent with the computer models. Our prediction about light bulb 2 is consistent / inconsistent with the computer models.

c. Explain what is happening when you close the switch (why the light bulbs change their brightness as the simulation shows?):

d. Three identical light bulbs are connected in a circuit as shown in Figure B. When you close the switch, compared with when the switch is open, the brightness of light bulb 1 will ___________, the brightness of light bulb 2 will _______________, the brightness of light bulb 3 will ________________.

e. Build the circuits using the software and test your prediction. Our prediction about light bulb 1 is consistent / inconsistent with the computer models. Our prediction about light bulb 2 is consistent / inconsistent with the computer models. Our prediction about light bulb 3 is consistent / inconsistent with the computer models.

f. Explain what is happening when you close the switch (why the light bulbs change their brightness as the simulation shows?):

(5) Ideal vs Non-Ideal Battery [extension]
a. Two identical light bulbs are connected in a circuit as shown in Figure C. Set a **real circuit** using a battery and two identical light bulbs. When you close the switch, you observe that the brightness of the light bulb 1 ________________.

b. Now using Phet, two identical light bulbs are connected in a circuit as shown in Figure C. According to the Phet simulation, when you close the switch, you observe that the brightness of the light bulb 1 ________________.

c. Now in Phet simulation, set the internal resistance of the battery (right click on the battery in the model) at some value. When you close the switch, you observe that the brightness of the light bulb 1 ________________.  [Adding internal resistance to a battery is as if you are connecting a resistor in series with the battery. This is similar to step (4). If you treat light bulb 1 in figure A as the internal resistance of the battery, then light bulb _______ in figure A corresponds to the light bulb 1 in figure C here. ]

d. Explain the difference between the voltages provided by an ideal battery (no internal resistance, typically, for a new battery) and a non-ideal battery (with internal resistance, typically, for a battery that gets old):

e. Do you think your household electricity power sources function as ideal or non-ideal battery? Explain.
APPENDIX F: HOMEWORK ON ELECTRICITY

1. After rubbing a balloon on the carpet, Sam brings the balloon near small pieces of paper without touching. Explain what will happen?

Explain:

2. The figure below shows the components of a device called electroscope. A rod is brought close to the electroscope. Answer the following two questions that are not related to each other.

(1) If the rod is negatively charged and is brought near the steel ball of the electroscope without touching, the strips of the aluminum foil will (circle one)
A. open  B. do nothing  C. stick together

Explain your choice:

(2) In a separate experiment, if the rod is positively charged and briefly touches the steel ball, the strips of the aluminum foil will (circle one)
A. open  B. do nothing  C. stick together

Explain your choice:
3. Three identical light bulbs (A,B,C) are connected as the following.

![Image of light bulb connections]

(1) Using parallel or series connections to explain how these light bulbs are connected.
(2) If the resistance of each light bulb is $10\,\Omega$; the voltage of the ideal battery is $3v$; calculate the following: (i) the current going through each light bulb, (ii) the voltage going through each light bulb, (iii) the electric power of each light bulb when being lit in this circuit. From these calculations, indicate the brightness of these three bulbs.

4. Two identical light bulbs (A,B) are connected in series as shown below. Then an additional identical light bulb C is added between points M and N. (1) Draw the electrical diagram when the light bulb C is added. (2) Indicate the change of brightness for both light bulb A and B and explain your predictions.