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CONSTRUCTION WITH CIRCUITS: A SEQUENCE OF LABORATORY EXERCISES, CLASSROOM ACTIVITIES, AND ASSESSMENT TOOLS CREATED FOR HIGH SCHOOL PHYSICS STUDENTS

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CONSTRUCTION WITH CIRCUITS: A SEQUENCE OF LABORATORY EXERCISES, CLASSROOM ACTIVITIES, AND ASSESSMENT TOOLS CREATED FOR HIGH SCHOOL PHYSICS STUDENTS

By

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ABSTRACT

CONSTRUCTION WITH CIRCUITS: A SEQUENCE OF LABORATORY EXERCISES, CLASSROOM ACTIVITIES, AND ASSESSMENT TOOLS CREATED FOR HIGH SCHOOL PHYSICS STUDENTS

By

Amy Lue Lindbeck

The purpose of the project described in this document was to study the effectiveness of an innovative sequence of activities, laboratory exercises, and assessments developed for use in a high school physics class study of electricity. The goals of this unit were twofold:

1. Students would be able to demonstrate their knowledge of the properties of electricity.
2. Students would be able to construct and design devices using the materials and methods practiced in the laboratory.

Students were given a pretest to determine their understanding of electricity concepts based on Michigan Essential Goals and Objectives in Science Education. The unit incorporated laboratory activities and new assessments developed at Michigan State University. Data were collected on student surveys and tests before beginning the unit and upon completion of the unit. Student homework responses and laboratory write-ups were also collected and analyzed. Success was measured as an increase in understanding as shown in laboratory performance and laboratory reports as well as classroom assessments, including a posttest.

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INTRODUCTION

I. Rationale for Study

As a biological sciences major with chemistry and mathematics minors, I have found high school physics to be the most difficult course I teach. I chose my first (and current) teaching assignment based on the wide variety of courses I would have the opportunity to teach, which has included algebra, advanced algebra, statistics and trigonometry, precalculus, calculus, chemistry, physics, and junior high science. While I do enjoy teaching physics, my experiences with the subject throughout the past five years have been most challenging. Electricity is the topic with which I felt most uncomfortable. I set out to learn more about the topic as well as to develop a better method for teaching my students.

As I learned more about electricity, I began to see the need for a new method of teaching that better met the needs of my students. I felt that students entering my classroom were grossly unprepared to study any physics concepts in depth, including electricity. MEAP test scores in science were low at my school, especially on the constructed response items of the test. Students seemed to be lacking in the areas that stressed higher order thinking skills. After having observed poor hands-on performance in the physics laboratory, I found that I was beginning to cut out laboratory activities because I saw them as a waste of time. As a whole, the quality of students' written work was often unacceptable.

Answers to test questions indicated students had done nothing more than memorize what was in their textbook on the topic.

Because my district operates on the four-block schedule, students meet with me each day for eighty-five minutes for a semester rather than each day for fifty-five minutes for the entire year. We miss out on total minutes of instructional time and are left with exhausted teenagers for well over an hour at a time each day. I felt as if I was trying to cram massive amounts of material into my students' brains during limited time.

When I put the above observations together with my own uneasiness with the subject matter, I felt compelled to develop my ideal unit on electricity. The unit would be engaging enough to keep students interested for the long class period, yet contain sufficient "substance" that students would be adequately prepared for their next level of instruction. The new unit would be more performance based, more hands on, and would require more use of higher order thinking skills. I also decided to change some assessment questions from the traditional rehearsed "regurgitation" exercises to conceptual explanations. In short, I wanted to focus my teaching of electricity more on the Michigan Essential Goals and Objectives in Science Education and build everything else around desired outcomes. The vehicle used to accomplish this task would be a series of activities and assessments based on the construction of five devices that are historically and functionally important to the study of electricity: the

Leyden jar, the light bulb, the chemical battery, the motor, and the speaker.

My spring semester physics class usually follows a very traditional outline beginning with Newtonian motion, states of matter, and energy. By the ninth week we have progressed to waves and optics. Electricity and magnetism are usually left for the last four weeks of instruction. This late in the year, all of my students have already taken the MEAP test, which takes place during May of the eleventh grade. In addition to changing the structure of the unit, I also decided to move it from late April to late March, a time of year when students would be less distracted and more willing to be engaged in instruction.

The learning goals of the unit were for students to: 1.) Describe how energy is conserved during transformations in natural and technological systems; 2.) Describe how electric currents can be produced by interacting wires and magnets; 3.) Construct and explain simple circuits using wire, light bulbs, fuses, switches, and power sources.

With these objectives firmly in hand, I set out to change the way students and I worked together during our unit on electricity.

II. Changing the Nature of Instruction to Maximize Learning Potential for Students

Since my goal was to help students effectively learn difficult concepts within a very short time period, setting limits in three major areas was vitally important to the success of my electrical energy unit. I wanted my unit to be limited in concepts addressed, limited in performance goals, and limited in length.

Where should the focus lie? Rather than dragging learning out into an endless comprehensive process, it is recommended that instructors should limit their common core of learning to ideas having the greatest scientific and educational significance for science literacy (Rutherford and Ahlgren, 1990). Contrary to what the thickness of our textbooks suggests, just a few main ideas should be a sufficient basis for a high school science unit.

A thematic unit also needs to be limited in the number of skills students are expected to demonstrate at one time. Although the breadth versus depth argument can be argued from both viewpoints, evidence suggests that choosing the most important concepts and skills to emphasize will allow the instructor to concentrate on the quality of understanding rather than just the quantity of the information being processed (Rutherford and Ahlgren, 1990).

Finally, reasonable time limits should be set. Learning each objective may be less difficult if students can see the light at the end of each tunnel along their road toward understanding. The act of providing students with opportunities to set short term learning goals assists students in self-examination of their progress in meeting their goals (Carter, 1999). I wanted my students to take ownership in their education. One way to accomplish this would be to engage students in minilabs. Minilabs are very brief, small-scale laboratory activities used in the classroom. The procedures for minilabs are often developed by students as part of a problem solving exercise. They allow for the planning, performing, and "making sense" of the experiment to be done by the students. This allows them to pose and answer their own questions in their own way (Genstone and Mitchell as quoted by Etkina and Horton, 2000).

An active approach to learning that utilizes everyday objects is strongly encouraged. After all, instructors want their students to have something they can use. According to Glasser (1969), a constant complaint of students is that schoolwork doesn't prepare them for living and surviving in the real world. All too often, classroom situations seem to be set apart from everyday life. Teachers are often guilty of asking students to regurgitate information. That isn't learning! Because research suggests that a majority of students have difficulty learning basic concepts in a course built around traditional lectures, textbook problems, and verification experiments, we need to improve learning by encouraging students to actively confront difficult concepts (American Association of

Physics Teachers, 1997). The laboratory is where a science student has experiences that interact with existing conceptions and at the same time develops new concepts (Gabel, et. al. 1994). An effective laboratory exercise gives students experience, not just exposure.

Allowing the students to take on the role of the investigator in the laboratory could contribute considerably to their conceptual framework. According to the National Research Council (1996), engaging students in inquiry helps them develop understanding of scientific concepts. It also instills in students an appreciation of "how we know what we know" in science.

For learning to be effective, it must be an active process in which learners construct new ideas or concepts based upon their framework of prior knowledge (Bruner, 1966). Employing this constructivist approach to one's teaching reinforces the idea that subtle guidance helps students make sense of material. Constructivist teachers strive to maximize opportunities for their students to express their points of view, reveal and reflect on their conceptions, and grow intellectually (Wyatt and Willis, 2000).

I began to plan my lessons according to the ideas outlined above. As it is important to plan multiple experiences related to each concept, teachers must ask questions that guide students to mentally construct the concept based upon the reality of their experiences (Guenther, 1997). Effective science teachers creatively modify activities to incorporate students' prior knowledge, engender active mental struggling with prior knowledge and new experiences, and encourage metacognition (Hand and Keys, 1999). Teaching strategies must be employed that help students to think and talk about the significances of their experiences. There needs to be a main objective understood by all before each laboratory experience begins, for until there is a clear question to answer by observation, students may not record what they see carefully enough (Driver, 1983).

Both activity and assessment during instruction must be closely monitored. I felt the need to supply the students with opportunities to constantly provide and respond to feedback from their experiences. Driver (1983) has an interesting yet simple perspective on learning: True learning has to be more than just activity for the learner; it has to make sense. Teaching strategies are needed which help pupils think and talk about the significance of their experiences and most importantly for teachers to talk through their experiences with them.

Guidance must take place during all stages of a successful project. Instructors need to provide instructional support in order for their students to be capable of actively and independently trying out different methods of working out problems. (Dufresne, 1997). According to Strain and Pearce (2001) students will always need guidance, yet encouraging them to take the lead seems to be the most effective and rewarding way of teaching.

Multiple forms of assessment are necessary because they help students in three major areas. First, summative feedback helps them to understand and locate the level of their achievement. Some of my students thrive on competition, and knowing where they stand may help them feel more motivated in the classroom. Second, formative feedback helps students with the learning process because it helps them to know what areas to work on in future investigations. Third, educative feedback helps students become more aware of how they learn best (Edwards, et al 1999). Eventually, it is hoped that students will forget about the grades and become totally engrossed in the subject matter. As Carter states (1999), if the learning rather than the performance becomes a goal of students, then the learning will naturally improve.

Eager to apply the above principles to my teaching style, I began the design of a new electricity unit for my high school physics students.

III. Demographics

This unit was taught in a rural district in which the closest city has a population of about 50,000. There are roughly 400 students in the high school, with 1500 students in the entire district. The total number varies within the school year, as the district loses students each fall and gains students each spring due to family migrations. The primary occupation of the area is farming, although many people are employed at the several industrial plants within forty miles of the school district. The physics class usually consists of ten to twenty students between the ages of sixteen and nineteen. Physics is an elective course that meets each school day for 85 minutes during the second semester in a block schedule. Three to four weeks are usually spent on electricity during the eighteen week semester. The unit reported here was taught once. Of the seventeen students in the class, twelve were female and five were male. Nearly all of the students were of Caucasian descent, with the exception of one foreign exchange student from Brazil. None of the students received special education services offered by the school district.

IV. Basic science principles:

The decision to select electricity as my unit topic was partly due to my own lack of confidence or knowledge in the subject area. An active approach where "less is more" was the method of choice for teaching the unit because I wanted to have my students model the method that I used. In my own search for a better understanding of the topic, I found that I learned best when the concepts seemed more concrete than the textbook presentation allowed. Reading the textbook and doing the problems alone did little to improve my understanding of electricity. Each time I taught electricity, I found that I was right back where I started the previous year with some quick memorizing to do before each lecture so that I could provide the correct answers to the questions I planned to ask in class.

Three ideas helped me gain a better conceptual understanding and consequently should help my students gain a better conceptual understanding about electrical energy. The first involved changes in the types of questions I asked. The second change was the introduction of more manipulatives into the learning environment. The third major change was my confrontation with common misconceptions in the subject area.

First, I began to focus on the "think" questions at the end of each section and chapter in the textbook's electricity unit. Although math problems are much easier to perform at the chalkboard and to grade on tests, I found the questions that dealt with each individual concept rather than the equations to be the ones that helped me to internalize what I'd just read or outlined in the text. In the past, I'd viewed electricity as a separate branch of science in which I had only a beginner's expertise. I was thinking more about what I did not know than what I did know. I had no framework for understanding this topic. By breaking it down into the basics, I was able to see that electrical energy was governed by the same basic conservation laws as other forms of energy studied in science. I was able to summarize each chapter into a few paragraphs. As my understanding increased, I was able to let go of the "chapter" idea and shift my focus to generating several summary statements about each topic. I forgot about the vocabulary and the equations and began to recognize patterns. Amazingly enough, it started to make sense!

Second, I became bolder with acquiring and manipulating equipment available to my students and me. For two years in a row I only performed one simple demonstration of series and parallel circuits. Each time, it involved two light bulbs and a power source and a few alligator clips. After taking some time on my own to hook up a few circuit boards with several light bulbs and even more clips and a dependable power source, I found that I could make better attempts at explaining the current, the voltage, and the resistance of each arrangement. A battery as a power source was easier to manipulate than the old plug-in sources available in my lab. The use of D-cell batteries also made the change in brightness of the light bulbs with each arrangement and addition of resistors more apparent. I also attended a workshop at the Muskegon

Area Intermediate School District; part of the Michigan Operation Physics series, and the topic was electricity. At this workshop, the presenter provided several simple and manageable hands-on science demonstrations that were easily adaptable for my classroom. Taking a turn at being the student allowed me to ask questions and try different scenarios with static electricity and with circuits. I left the workshop feeling much more confident and full of ideas for practical yet safe demonstrations and laboratory investigations to undertake with students of all ages. Some of these ideas were tested at Michigan State University as part of my research for this thesis.

Third, I read. I found it very beneficial to be able to read through three different perspectives on an activity so that I could eventually try it on my own and adapt a format that would fit into my instruction. My research included not only investigating different activities, demonstrations and laboratory investigations, but also gathering articles and reading what the experts had to say about how and why students do or do not learn. I used this opportunity to investigate the different misconceptions students often held about electrical energy (similar to my own misconceptions!). From there, I began to work on a way of improving this conceptual model for both my students and myself.

Electricity is a form of energy that results from a separation of positive and negative charges. Students should know that it's the movement of electrons, not protons, that makes this possible. Some materials, such as metals, do not hold their electrons close to the nucleus of each atom and easily allow electrons the transfer of electrons from atom to atom. These materials are called conductors. Insulators are materials that hold their electrons closer to the nucleus of each atom and do not easily allow electrons to be transferred from atom to atom.

Electrical energy transformed from or to another energy source in any system; sometimes from mechanical energy as with a generator, sometimes from chemical energy as with a battery. Just like mass and momentum, the total amount of energy in the universe is conserved. Energy cannot be created or destroyed.

In a battery, the making of a complete wire circuit connects the two halves of the battery so that the chemical reactions inside can proceed. One chemical reaction produces electrons and the other requires electrons. The wire becomes a one-way path for these electrons to move from one section of the battery to the other. The electrons themselves are moving relatively slowly, but the rate at which the energy from this movement of electrons is being transferred through the wire (called current) can be quite rapid. The movement of electrons provides energy that can be converted to other forms when devices are connected to the battery's circuit. When a battery wears out, the chemical reactions have been depleted, and electrons are no longer being sent through the wire. The amount of energy transferred by the electrons in a circuit is called voltage. Voltage is expressed in joules per coulomb of charge.

All electrical energy is a result of the movement of electrons. Static electricity does not mean that electrons stand still; it's just a title given to the type of situations where the electrons "jump" from an area of high concentration to an area of low concentration without a wire as their conducting path. Current electricity is a term used to describe the movement of electrons where the electrons travel through a wire path called a circuit.

Electric circuits can be made with resistors in series, parallel, or a combination of the two. Resistors are devices that impede the flow of electrons through a circuit. Light bulbs are examples of resistors. When in series, each resistor is another "roadblock" along the one loop from start to finish along the circuit. The addition of resistors increases the total resistance and therefore makes the uniform current through the circuit less. Adding resistors in parallel adds more pathways for the electrons to travel from start to finish in a circuit. While the combination of two resistors of ten ohms each in series results in twenty ohms of equivalent resistance; combining the two of them in parallel yields an equivalent resistance of 1/ (1/10 + 1/10), or 5 ohms. The current through each resistor may be different in parallel circuits, as they are separate pathways.

A concentration of electric charges exerts a force on nearby charged objects in the form of an electric field. Like a magnetic field, an electric field exerts a force on objects according to an inverse square law.

The movement of an object within a magnetic field can produce electrical energy, while introducing electricity within a magnetic field can produce mechanical energy. Although electric and magnetic fields exist separately, they can be combined in a motor to convert chemical electric energy into mechanical energy and in a generator to convert mechanical energy into electrical energy and are both components of light energy.

IMPLEMENTATION OF THE UNIT

I. Overview

At the beginning of the semester, students were informed of the upcoming project we would be doing on electricity. Four weeks into the semester, I handed out and began collection of my student permission slips. Two days before I began teaching the unit, students were given an opportunity to complete a survey form (Appendix A) and a pretest (Appendix B1) in the intended area of study. For the purposes of this study, these responses were compared to student responses on a similar survey and test given the two days after instruction of the unit was completed. The two sets of results were analyzed to determine whether or not significant learning had taken place during the ten days of the unit. Other electricity unit assessments not analyzed as part of this study include a quiz (Appendix B2) and test (Appendix B3). These two assessments were not analyzed as part of this study, as they were not a result of new teaching techniques or new laboratory exercises. They were much the same as assessment tools from previous years.

Each of the following three objectives for the unit was taken from the Michigan Essential Goals and Objectives for Science Education. Benchmarks and Standards were also used.

1. Describe how energy is conserved during transformations and natural and technological systems.

2. Describe how electric currents can be produced by interacting wires and magnets.

3. Construct and explain simple circuits using wire, light bulbs, fuses, switches, and power sources.

A set of five construction laboratory exercises (Appendix C) and five supplemental activities was developed as a result of my coursework and research at Michigan State University (Summer 2000). Each was designed and selected with the intention of engaging the students and helping them develop a deeper, more practical understanding of the properties and uses of electrical energy.

To complete the activities and exercises, students worked in groups of two to four. Students were required to record all results on their laboratory handouts or include them in their laboratory write-ups. After completion of each exercise, a class discussion of the results would take place.

Class periods began with review exercises designed to reinforce concepts introduced throughout the unit. The review exercises ranged from a set of short definitions of concepts discussed during an earlier class period during the unit to an application question that was based on what the students had accomplished earlier in the unit. Students were given the opportunity to write down any additional inquiries they had regarding electrical energy; these extra questions were addressed later in the unit. Students were encouraged to take notes during these times, as the review material was "fair game" for future assessments.

After the series of construction laboratory exercises and activities was completed, tests were given to measure student learning. The pre and posttest focused on an understanding of electrical energy in terms of charge separation, conductors and insulators, conservation of energy, series and parallel circuits, and motors and generators. The pre and post survey focused on student attitudes toward laboratory activities, laboratory reports, and performance-based assessment.

Many new teaching techniques were developed and implemented as a result of my research project. They can be summarized as: 1) review of previous material in a variety of formats; 2) short activities supplemented lecture material each day; 3) variety of laboratory formats including prelab questions, construction activities, reflection questions, calculations, and laboratory write-ups.

II. Basic Outline

This unit on electricity required ten days of instructional time in a block schedule with eighty-five minute classes, which is equivalent to approximately fifteen days in a normal fifty-five to sixty minute class schedule. The activities, laboratory exercises, and assessments were either made or revised during my research at Michigan State University (Summer 2000). Pre and Post Tests (Appendix B1) were given before the first and after the last day of instruction, as well as Pre and Post Surveys (Appendix A). A complete copy of each laboratory exercise can be found in Appendix C. Each laboratory exercise and support activity is listed according to Concept in Table 1.

Table 1. Lab Exercises and Support Activities by Concept Addressed

Concepts	**Construction Lab Exercises (Appendix C Location in Parenthesis)**	**Support Activities**
Charge	Making a Leyden Jar (C1)	What is the Charge on an Electron? Millikan Oil Drop Simulation
Current	Making a Light Bulb (C2)	What's in a Light Bulb? The Anatomy of a Light Bulb
Circuits	Making a Chemical Battery (C3)	What is the Path of Least Resistance? A Comparison of Series and Parallel Circuits How Does it All Match Up? Electricity Poster Project
Electro-magnetism	Making a Simple D-Cell Motor (C4) Making a Cheapie Speaker (C5)	How Can We Picture an Electric Field? Modeling with Magnets

III. Evaluation Protocols

Four levels of assessment were used in determining the overall effectiveness of the unit. The first level was the pre and post test (Appendix B1) scores for those seventeen students who participated in the study. The pre and post tests were analyzed based on responses to five short essay questions. It was important for the students to have the opportunity to present their knowledge in their own words.

Laboratory reports were the second level of assessment for the unit. The written response questions for each exercise were designed to measure the effectiveness of the laboratory exercise in facilitating student mastery of the learning objective(s) addressed.

The third level of assessment for the unit included student feedback in the form of classroom assignments, both example sheets and review worksheets. These interactions between the students and me allowed for fine adjustments of the format each day to meet the needs of the class.

To evaluate student attitudes on the different laboratory exercises and on the different modes of implementation, I conducted a pre and post unit survey (Appendix A) on student opinions of laboratory exercises, laboratory reports, and performance-based assessment. In addition, this survey also allowed students to rate their own confidence in their ability to meet each major objective addressed throughout the unit.

IV. Construction Laboratory Exercises and Supplemental Activities: Description and Analysis

Appendix reference of accompanying student handout for each construction laboratory exercise is in parenthesis.

Supplemental Activity 1. Anatomy of a Light Bulb

During this activity, students used a hammer to break an old household light bulb wrapped in a towel. Glass from the bulb was disposed of by emptying the contents of the towel into the laboratory glassware disposal container, then students then observed the parts of a light bulb and traced the circuit from where the electrons enter the bulb to where they exit.

Before given their bulbs, students were asked to quickly sketch diagrams with arrows to show what happens to provide electrical energy when a light bulb is turned on. Approximately 25% of the drawings were unclear about the fact that it's an electrical circuit through the bulb rather than an electricity supply running to the bulb. This indicated that some students shared a misconception that electricity is like water from a hose in that it comes from the source and is used in the vessel.

Upon breaking and examining real light bulbs, students had the opportunity to confront their misconception and to see for themselves that the filament is just the middle part of a pathway through which electric energy travels when electrons are excited.

After completing the activity, students left their bulbs in the laboratory and returned to their seats, where they were presented with new material on atomic structure, conductors and insulators. As part of classroom lecture and recitation, students learned about the structure and function of both fluorescent and incandescent light bulbs.

Construction Laboratory 1. Making a Leyden Jar (C1)

The objective of the first laboratory exercise was to allow students to practice working with a combination of conducting and insulating materials in order to store electric charge. Students worked in groups of two. Materials for the lab had been set out for students before the class period began: assembly of the devices took less than ten minutes. The write-up for the lab did not include any diagrams, and students did a wonderful job with their constructions without a picture as a guide. The only mistake made was failure to cover the bottom of the canister as well as the sides with foil. This mistake was corrected by instruction before the device was tested.

After manipulating their Leyden jars, students began to work on answers to the constructed response question at the end of the lab write-up. After being encouraged to explain their interpretation of their observations to their lab partners, students were provided with the handout "How the Leyden Jar Works" (C1). There seemed to be no mistaking the fact that it was the movement of electrons that caused the shocks and sparks. The class period ended with an introduction to some of the electricity terms such as charge separation, grounding, and capacitance used in the section of their textbook that were relevant to the laboratory exercise they had just completed. Students were asked to read the chapter on electric charge in their text for the next day.

Supplemental Activity 2. Millikan Oil Drop Simulation

This laboratory exercise was intended to accomplish several things. First, it allows students to experience technology in the classroom as they use a program that is compatible with our school calculators. Second, it provides experience with completing a laboratory report. Since science is a process, doing the lab write-up helped facilitate student analysis of the activity. Third, the calculations help students derive the charge on an electron from authentic experimental data.

Students had no difficulty manipulating the calculator program. The calculations, though, were quite rigorous and worked out best with a sample of each done on the overhead projector prior to students analyzing their own results. The calculations took a total of one hour of instructional support the following day.

The added section to this activity was the student response question section at the end. Besides a conclusion and sources of error, students were asked to address the significance of knowing the charge on an electron and whether they thought the real Millikan Oil Drop Experiment was worthy of the 1923 Nobel Prize in Physics.

Construction Laboratory 2. Making a Homemade Light Bulb (C2)

For this exercise, students worked in groups of three to four. With the exception of filament wire, materials had been set out ahead of time. Students met with much frustration during this laboratory, mainly because the ideal filament wire was not available for their use. Because all of the available wire was too thick, the coiled wire filament did not glow well. While steel wool definitely glowed, strands of steel wool were too thin to retain a coiled shape when taken off the golf tee. Steel wool also burned out too quickly.

Students were asked to address a series of six questions after working in the laboratory. Because the focus primarily had been on getting the filament to function, students did not have the time to compare or measure to obtain concrete results.

Supplemental Activity 3. Electric Field Model

Students were given ceramic magnets, a piece of paper, and a film canister that contained iron filings. They were to sprinkle the filings on top of the magnet with the paper between the magnet and the filings and observe patterns. Students were informed that they would actually be observing magnetic fields, which are similar to and interact with electric fields.

This short activity required little guidance and, although students were observing effects of magnetic fields, the activity made their concept of an electric field much more concrete. The arrangement clearly showed greater concentration of filings in the areas where the field was stronger and absence of filings in the areas where the field was weak.

Construction Laboratory 3. Making a Chemical Battery (C3)

The day before this exercise, students filled out a series of prelab questions. The questions encouraged students to think about what makes one material a better conductor of electricity than another as well as to learn about the basic purpose of some common electrical devices such as ammeters, voltmeters, and galvanometers. Immediately prior to students entering the lab, the class discussed their responses to the prelab questions.

In spite of old and barely functioning galvanometers, this activity proved that ordinary lemon juice and vinegar are able to conduct electricity. One group even tried water from the tap and was amazed to find that it, too, conducted electrical energy.

Supplemental Activity 4. Resistors in Series and Parallel

Students were asked to work in groups of two to three to set up four small light bulbs in series and in parallel. Prior to the activity, students made a comparison chart for series and parallel circuits based on information from their textbook. Since the comparison chart contained a diagram of each type, students had very little trouble setting up the circuits. What seemed to amaze students most about the parallel circuit was the idea that one bulb could be taken out and the others would still function.

This activity was also intended to serve as an opportunity to observe difference in the overall brightness of four bulbs in series and in parallel. Not all groups seemed to be able to understand the connection between bulb brightness and equivalent resistance.

Construction Laboratory 4. Making a D-cell Motor (C4)

Batteries, wire, paper clips, rubber bands, and magnets were the only necessary materials for this laboratory exercise. Students were very curious about how the materials could possibly produce a working electrical motor. Students worked in groups of two to four.

The day before the lab, they were given approximately fifteen minutes to attempt building a motor based upon a brief verbal description. Only one group was able to get their motor to function.

On lab day, students were given a more detailed description of what must be done to ensure that the motor functions properly as well as a set of three questions to answer upon completion of the lab. This was designed to take thirty minutes, but their substitute teacher did not adhere to the guidelines in my lesson plan and allowed students extra time to experiment. Students appeared to enjoy the extra time to complete the task, but other parts of the unit were rushed in order to fit them into the specified ten day instruction time.

Supplemental Activity 5. Electricity Poster Project

While working in groups of two to four, students were to generate a short matching game as a review of terms, equivalent units, and historical discoveries they had studied during their unit on electricity. This matching game was to be displayed on a poster that, when wired properly, would have a bulb that lights up when selections off the menu are matched correctly.

Materials for this activity were relatively inexpensive. Small brass tacks (brads) from the school supply room worked well as connecting posts. The rest of the circuitry was composed of alligator clips, a 9-volt battery, and one light removed from a strand of holiday lights.

Although the student-generated questions and answers displayed on the posters were fairly basic, students became very elaborate and original with the design of their posters. This assignment provided an opportunity for their creativity to shine through.

Construction Laboratory 5. Making a Cheapie Speaker (C5)

With this laboratory exercise, students were given the opportunity to do some research from their text in order to answer some prelab questions, discuss their predictions, then eventually build and test their device. Afterwards, they examined the design of a dismantled pair of stereo headphones to verify that it contained the same basic components as their homemade speakers did.

Prelab responses indicated that students felt coil length was most important to the working of the speaker. During the exercise, though, they seemed to be in agreement that proper placement of the electrical components near the magnet contributed the most to production of the best interaction between the electric and magnetic fields.

The time required for completion of this exercise was difficult to estimate. Since there was only one radio available in the classroom for testing the speakers, students were encouraged to work in groups on their poster activity (Activity 5 above) until the radio was free for testing. This allowed students to make the best of the time provided in class to wrap up the laboratory constructions and supplemental activities.

EVALUATION

I. Pre and Post Test (Appendix B1)

The questions on the pre and post tests were written as a combination of five short answer and essay questions that could demonstrate learning of electricity concepts. The questions addressed the difference between static and current electricity, the elementary particle responsible for electricity, the contents and function of a battery, resistance in series and parallel circuits, and the relationship between electricity and magnetism.

The tests were administered the day before the beginning of the unit and the day after completion of the unit. Each question was scored with the rubric shown in Table 2. The mean test scores for each item on the pre and post test are shown in Table 3. The mean test score increased for each of the five test items.

Table 2. Rubric used for scoring Pre and Post Tests

Question #1: True or False? Justify your answer. Electricity comes in two types: static and current.

Response	Score
Just true	0
True with real life examples	2-2.5
Just false	2
False with examples or definitions	3-4
False with examples and definitions	5

Question #2. What "travels" through the wires of an electric circuit when an appliance is running? Explain.

Response	Score
Blank or unacceptable response	0
Electricity or Current	1
Electrons (may include speed as well)	2.5-3.5
Energy due to electron movement	4
Electrons slowly but energy quickly	5

Question #3. What happens to make a chemical battery wear out? Where does the energy go?

Response	Score
Don't know	0
Chemicals/Energy leak out	1
Chemicals used/electrons lost	2
No electrons moving or reaction complete	3
No electrons moving because reaction is complete	5

Question #4. How and why does the resistance of a series circuit differ from that of a parallel circuit when additional resistors are added?

Response	Score
Don't know	0
Description of bulb brightness	1-2
Decrease parallel with equations	3.5
Decrease parallel with explanation	5

Question #5. How are electricity and magnetism related? Use a motor and/or generator in your explanation.

Response	Score
Don't know	0
Depend on each other	1
Coexist	1.5
Description of motor/generator with relationship	3-5

Table 3. Pre and Post Test Data

Response Item	n	Mean Pretest Score (5 possible)	Mean Posttest Score (5 possible)	Increase in Mean
1	17	1.11	3.35	2.24
2	17	1.82	3.29	1.47
3	17	1.04	2.48	1.44
4	17	0.29	3.18	2.89
5	17	0.64	2.47	1.83

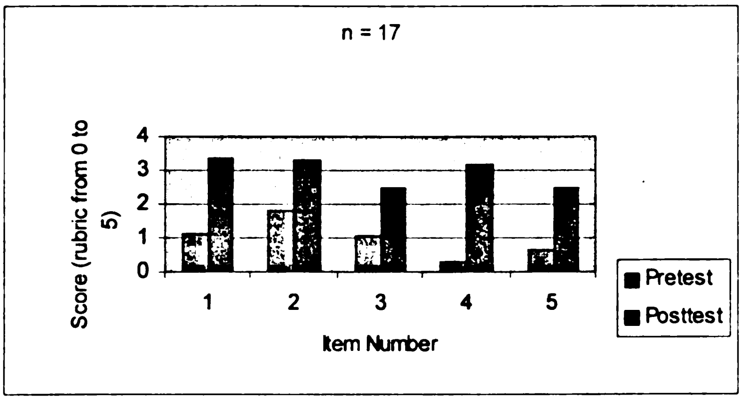
Overall, the nature of student responses progressed from short statements that were mostly incorrect to paragraphs that were mostly correct. When asked what travels through the wires of an electric circuit when an appliance is operating, one student revised her original "electric currents" response to "Electrons travel from atom to atom throughout the wires. They don't travel very quickly because they don't need to. There are electrons that are always in the wires. When the switch is flipped new electrons are added to that end and others are pushed out the other end and causes the appliance to run." Another student, when asked how electricity and magnetism are related, progressed from an initial "Okay, in a motor, it uses the force of magnetism to produce the electricity to make the motor run." to "They are related because as in a motor, with the coil in the motor we made the electricity work with the magnet to keep the wire in motion – electricity provides the energy and magnetism provides the motion." In response to a question that asked the student to tell how and why the resistance of a series circuit differs from that of a parallel circuit when additional resistors are added, a third student originally stated, "No Clue!". Later, the same student responded with "In a series circuit there is one path for the electrons to move through unlike the many paths in a parallel circuit. So when a resistor is present in a series circuit the electrons must overcome it in order to complete the circuit. In a parallel circuit if a resistor is present the electrons "search" for the path of least resistance. Thus there is a much better opportunity for the electrons to move along a path of less resistance in a parallel circuit than series when additional resistors are added to the existing circuit."

Unfortunately, not all students showed dramatic improvements in their ability to explain concepts. For example, typical before and after responses to the question regarding what happens when a battery wears out included "The juice runs out." and "The energy is used up." This item was especially frustrating from a teacher's standpoint, as both the conservation of energy and transformation from one form to another within a system is addressed many times at earlier grade levels, as well as during physics class.

Many responses indicated that students remained confused about the concept of resistance. In their explanations of how series and parallel circuits differ with the addition of more resistors, many concentrated so much on bulbs that they forgot to address the question. Students seemed to be concentrating their efforts on explaining that series circuits are unable to function when a bulb is burned out and that overall bulb brightness changes when another bulb is added.

A graph comparing the pre and post test averages for each of the five response items is shown in Figure 1.

Figure 1. Pre and Post Test Mean Scores.



II. New Teaching Strategies

The use of construction exercises in the physics laboratory along with supplemental learning activities appears to facilitate student learning, as indicated by the pre and post test results. In order to determine whether the change in class test results was statistically significant, a Student's *t* test was performed on the data (Table 4).

Table 4. *t* test Results Comparing the Pre and Post Test Scores for each of the Five Response Items on the Test.

Data where H_o: $\mu_1 = \mu_2$ and $\alpha = .01$	**Degrees of Freedom**	**t test**	**Reject or Accept H_o (no difference between pre and post test scores)**
Pre test item 1 – Post Test item 1	32	5.413	Reject
Pre test item 2 – Post Test item 2	32	3.560	Reject
Pre test item 3 – Post test item 3	32	3.257	Reject
Pre test item 4 – Post test item 4	32	8.130	Reject
Pre test item 5 – Post test item 5	32	3.688	Reject

The results show that there was a significant increase in the average of the test scores on each response item. In studying the answers given by students on the pre and post test items, there were positive changes in both the content and the depth of their explanations.

Responses to laboratory questions also reflected depth in student understanding. When asked to state some properties of zinc and copper that would make them ideal parts of a chemical battery, one typical (and accurate) student response was "zinc and copper are metals so they hold their electrons less tightly than nonmetals making them good conductors of electricity". Another student, when asked in a prelab question why saltwater would act as a good conducting medium in a chemical battery, responded with, "Perhaps, since the salt contains sodium which is a metal, it may happen to increase the conductivity in the water. An electrolyte is a conducting medium in which the flow is accompanied by the movement of matter too."

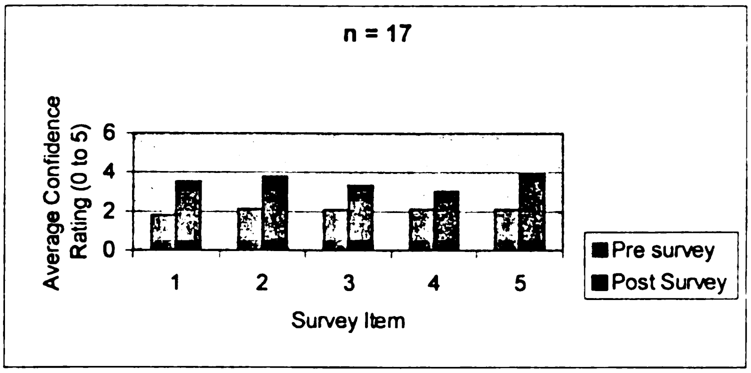
III. Student Evaluation

Students were given a survey (Appendix A) which contained three questions regarding their attitudes toward physics laboratory exercises and also provided an opportunity for students to rank their perceived skill level in meeting the unit objectives on a scale from zero to five, five being the most proficient. Student perceived skill levels increased on all five items they were asked to assess. The results of the surveys are shown in Table 5 and Figure 2.

Table 5. Pre and Post Survey Data

Survey Item	Number of responses	Mean score before unit	Mean score after unit	Increase in mean score
1. static and current electricity	17	1.82	3.56	1.74
2. complete circuits	17	2.12	3.81	1.69
3. relationship between wire, magnets, and current	17	2.06	3.38	1.32
4. properties and function of motors and generators	17	2.12	3.06	0.94
5. properties of series and parallel circuits	17	2.12	3.94	1.72

Figure 2. Mean Rankings of Pre and Post Survey Items.



A student's *t* test was performed on the mean pre survey score and mean post survey score for each item to determine whether or not student confidence had increased significantly. Results of the test are shown in Table 6.

Table 6. *t* test Results Comparing the Pre and Post Survey Scores for each of the Five Response Items on the Survey.

Data where H_o: $\mu_1 = \mu_2$ and $\alpha = .05$	**Degrees of Freedom**	**t test**	**Reject or Accept H_o (no difference between pre and post survey scores)**
Pre survey item 1 – Post Survey item 1	32	2.036	Reject
Pre survey item 2 – Post survey item 2	32	1.360	Accept
Pre survey item 3 – Post survey item 3	32	0.898	Accept
Pre survey item 4 – Post survey item 4	32	0.607	Accept
Pre survey item 5 – Post survey item 5	32	1.270	Accept

Both before and after the unit, students felt overall that they learn better in a science class where laboratory activities are used often. Typical student comments for over half of the class included "It helps you to relate concepts we learn to real life.", "I have a hard time comprehending just words a lot of the time and I like to see and touch things rather than to hear.", and "The more applied to the subject the better I learn through hands on.". On the other hand, other students expressed negative opinions regarding laboratory activity and learning.

One student wrote, "Explaining from simple examples usually works better.". Another wrote, "I don't think it makes much difference.". A third student responded with, "I never really learned what I was supposed to learn from lab".

Students had varying views of the laboratory report as a learning tool for science. Many felt certain that the report did nothing to facilitate learning. One typical response was "I think summaries are much better when they are just discussed. Writing it down seems like a waste of time." Other more positive comments included "I don't like doing them, but they can help to learn what we did in the lab." and "reports are a helpful way to organize the material we covered but lengthy written reports of easy to understand material seem tedious".

When asked about their views on construction tasks in the laboratory where time constraints were present, students seemed to be very vocal about not being in favor of time limits. I found this surprising, as during the entire unit I felt that I had allowed more than enough time for each activity. A representative student opinion is "Not in a specific time period because labs seem to be about learning from mistakes and getting the best trials one can. It's not bad if we're rushed a little but it's frustrating when we don't have much time at all."

DISCUSSION

I. What was Effective

Evidence from the pre and posttest indicates significant learning has taken place during the teaching of this unit. One can surmise that students learned about electricity by completing the activities and construction laboratory exercises. One of the fundamental features of the unit was an active approach. Many of the correct student explanations on the posttest supported this way of learning because they contained references to activities performed in class. Students overwhelmingly indicated on the post survey and during class discussion that they favored "hands-on" learning over the traditional approach. Even after the unit, students were begging for more labs. I felt that during this unit I was finally able to meet the needs of my students.

Overall, students' attention did not wander from the main topic when this unit was taught. They seemed to be more focused than usual. I attribute this to the nature of the laboratory exercises and the supplemental classroom activities and reviews. Short labs were effective for the unit, as the student's *t* test indicated significant learning had taken place even under the limited time constraints. Cutting through some of the red tape of preparing laboratory notebooks allowed us to accomplish the equivalent of four to five textbook chapters within ten days of instruction. The use of a variety of short in-class reviews was helpful as well. Having the reviews take place at the beginning of a class period helped us narrow down where we needed to go during each day's instruction. The short review of the previous day's material gave also students a chance to reflect on the material from the previous day and provided a safe environment for students to ask questions. Through experimentation with a variety of different review formats, I too began to feel more interested in teaching the material.

II. Changing the Teaching of Other Units

Without a doubt, I am certain that my teaching style will change as a result of this study. I am certain that students learn well from concrete hands on learning experiences, much more certain than I am that students learn well from the traditional "chalk and talk" classroom setting. Students learn well with a visual representation of the information, and I plan to include short introductory demonstrations, laboratory activities, and supplemental activities that focus more on students being able to picture a concept in every subject area. My focus has shifted from the need to fit everything in with my semester time limits to the need to make everything fit into student understanding of basic concepts.

I feel that my teaching style will become more creative overall when it comes to review formats. Those first few minutes are unbelievably important: the task is to help students focus on the topic right away and set the tone for the rest of the class period. In the future, I would like to employ just as much variety at the end of class for a wrap-up as well.

Due to my newfound appreciation for the writing process as a learning tool, I will continue to ask students to put their predictions and ideas on paper before engaging in a classroom activity. Even when I put thought questions on the board, I will have students jot down a brief description of what they would say if called on to share their thoughts with the class. I feel that it helps facilitate concept development. Future lab write-ups for my other classes may include more prelab thought questions for students to answer before entering the lab as well. In general, prelab questions help students become familiar with the procedure and the objectives of the lab. Extension questions will help students improve their skills in interpreting the meaning of their results. I'll also make a point of taking time out to discuss each laboratory exercise immediately afterwards – even five minutes to discuss results (rather than just report their scores later, as I often had done in the past).

If possible, I'll try to shorten laboratory exercises to thirty minutes or less so that there will be time for discussion during the same class period after students complete the activity. There's nothing like immediate feedback to transform an activity into a valuable learning experience.

There are many valuable organizational strategies I learned during the development and implementation of this unit besides just shortening the procedure for the lab. A folder of make-up work and summary of each class period's activities must be available to students prior to and after absences. Conveniently placed and labeled storage containers for laboratory equipment shaves time off both setup and cleanup. Supplies such as graph paper, calculators, and pens need to be easily accessible in the classroom for each laboratory group's immediate use. Laboratory groups should also be set up ahead of time and posted in the classroom.

In the future, I will be confident to go beyond the text with a topic. I feel more confident about using the Internet and about having my students do projects. I feel that it's okay for me not to know the correct textbook answers to all of their questions the instant they ask them. Instead, my not always knowing the answer right away serves to model a learning process because students are able to see me give my own prediction in the form of a hypothesis, replacing it with a researched answer the next day. I feel as though I can make learning more meaningful for my students by not being afraid to step out of my comfort zone.

III. Aspects that Need Improvement

Too much of the laboratory activity in this unit was not supported adequately with text assignments. The ten day limit allowed for very little repetition of skills or concepts. Students do not always retain what they read; they may not understand the importance of the material in a chapter; they may not take the time to study the material – unless it is incorporated as part of an assignment. Next time around, this unit will take 12-15 days to complete because we will take more time in class to reinforce concepts. We will practice doing more problems and explaining answers to more essay questions. More instructional support materials for students as well as more time for completing and discussing activities will help students be better prepared for assessments.

Questioning needs to improve during the next implementation of this unit. While everything in this unit was designed around a central theme, I need to double check to make sure that everything is like a spider web woven around my objectives. In my fear of "teaching to the test", I feel that I may have overlooked the importance of referring to the pretest questions during the unit rather than just before and after. Perhaps I was making a mistake in thinking that I would be cheating if I provided feedback to the pretest questions in class. Talking the pretest over with the students would have helped them to better understand the objectives. My student survey questions will be revised next time to be better aligned with the pretest and posttest items. With a direct correlation between the test and survey, these tools may be useful as diagnostic instruments for determining ways of getting perceived and actual skill levels to improve equally in each concept area.

While student confidence on each of the five survey items did increase, the student's *t* test indicated that there was a significant increase in only their confidence in distinguishing between static and current electricity. I interpreted these results in a positive way, as students may have been overconfident before beginning the unit and more humble afterwards.

The daily schedule could be better organized as well. One problem I battled during the teaching of this unit was student attendance. Although all cases involved excused absences, several students missed important instruction time and never quite recovered from the lost time. I felt that the traditional method of having them copy another student's notes or completing a make up worksheet was ineffective due to the active nature of each class period during the course of this unit. To keep these students from falling too far behind, I need to have a folder of handouts and class discussion summaries as well a portable kit for each laboratory activity prepared in advance. I also need to be more aggressive in working with students and parents to schedule make up activities before and after school. If I want to have students who are accountable for making up missed time, I need to make it a little easier for them. Reteaching the material four or more days later after school to one student seemed ineffective because the elapsed time made the days melt together.

In the future, I plan to choose activity and laboratory groups for students. While they were comfortable with the groups and there were no behavior problems, students were almost too comfortable. Modest mismatches within and between groups may help bring out competition in students.

IV. Conclusions

My experiences in teaching this unit have allowed me to see firsthand the fact that learning occurs at a deeper level when students engage in active laboratory experiences coupled with reflection questions with time allowed for classroom discussion. The fact that the mean pre and posttest scores were significantly improved with a 99% confidence level as indicated by the student's *t* test was monumental. Through the teaching of this unit, I have come to appreciate the importance of writing as part of the learning process in science. I now think of writing as essential to both concept formation and concept reinforcement.

Planning and preparation are vital to the success of all laboratory experiences. Laboratory investigations must be planned carefully in order to meet desired outcomes; the instructor must analyze pre-lab questions before students begin the actual exercise. Effective teaching is very personal, and I can best facilitate student learning if I am aware of each student's level of knowledge before instruction and before the test. Effective teaching appears to involve a great deal of research on each learner as well as the subject matter. During instruction, the teacher ideally knows the skill level of those being taught. After instruction has taken place, the test merely serves as a place for students to display their new knowledge.

I enjoyed my new style of teaching. I did not feel overwhelmed by the amount of material I needed to present to the class and I appreciated the simplicity of the "less is more" approach. I look forward to employing my new methods and techniques in other units.

I am pleased with the student learning outcomes resulting from the implementation of this new unit on electricity. I am pleased with my own improvement in teaching ability as well. I know that I have learned some valuable lessons and have no doubts that this study has proven beneficial to both my students and me.

APPENDIX A

Physics Student Survey: **Name____________________**

1. Do you feel that you learn better (*i.e. get the big picture*) in a science class where labs are used more often? Why?

2. How do you view preparing lab reports as a part of your learning process in science?

3. Do you think you learn well from performance-based tasks where you are required to build or demonstrate something in science within a specified time period? How?

4. How confident are you in your ability to do the following?

1	2	3	4	5
(not)		(somewhat)		(very)

Skill	Confidence
1. Describe the nature of and relationship between static and current electricity.	
2. Explain the purpose and function of fuses and switches in an electric circuit	
3. Describe how electric currents can be produced by interacting wires and magnets.	
4. Compare and contrast motors and generators.	
5. Construct / explain circuits using wires, light bulbs, fuses switches, and power sources.	

APPENDIX B1

Electricity Pretest----------------------Name________________________

1. True or False? Justify your answer. Electricity comes in two types: static and current.

2. What "travels" through the wires of an electric circuit when an appliance is running? Explain.

3. What happens to make a chemical battery wear out? Where does the energy go?

4. How and why does the resistance of a series circuit differ from that of a parallel circuit when additional resistors are added?

5. How are electricity and magnetism related? Use a motor and /or generator as part of your explanation.

APPENDIX B2

Physics Electricity Quiz #1 -------------Name______________________

1. A positive charge of $3.6 \times 10^{-5}C$ and a negative charge of $-2.4 \times 10^{-5}C$ are 0.34 m apart. What is the magnitude of the attractive force between the two particles?

2. The force between two objects is 64 Newtons. One has a positive charge of $1.4 \times 10^{-6}C$ and the other has a charge of $1.8 \times 10^{-6}C$. How far apart are the two objects?

3. Two negative charges of $-4.2 \times 10^{-8}C$ are separated by 0.46 m. What is the magnitude of the force acting on each object?

4. Two objects exert a force on each other of 4.2 N. The distance between them is 0.36 m. The charge on one object is $2.8 \times 10^{-9}C$. What is the charge on the other object?

5. At the atomic level, what makes a particle a good conductor of electrical energy? What is it about metals that make them better conductors than nonmetals?

APPENDIX B3

PHYSICS ELECTRICITY TEST ---------Name______________________

1. The electric force between two objects is 64 N. One has a positive charge of 1.4 x 10^{-6} C and the other has a negative charge of 1.8 x 10^{-8} C. How far apart are the objects?

2. Two objects, one having twice the charge of the other, are separated by 0.78 m and exert a force of 3.8 x 10^{3} N on each other. What is the charge on each object?

3. What charge exists on a test charge that registers a force of 3.60 x 10^{-6}N at a point where the electric field intensity is 1.60 x 10^{-5}N/C?

4. A voltmeter connected to two parallel plates registers 38.2 V. A distance of 0.046 m separates the plates. What is the strength of the field intensity between the two plates?

5. How much work is done to transfer a 0.47 C of charge through a potential difference of 12 V?

6. What voltage is applied to a 6.80-ohm resistor if the current is 3.20 amps?

7. An electric blanket with resistance 8.6 ohms is connected to a 120 V source. What is the current in the circuit?

8. How much heat does the above blanket produce in 15 minutes?

9. Three resistors are connected in parallel. R1 = 5 ohms, R2 = 15 ohms, and R3 = 10 ohms. The potential difference is 12 V.
   a. What is the equivalent resistance?

   b. What is the overall current in the circuit?

   c. What is the current through R1?

10. How much power is required to charge a capacitor of 9.4 microfarads to 540 volts in 48 seconds?

APPENDIX C1

Making a Leyden Jar

In this activity you will make and analyze an inexpensive model of the Leyden jar, the first device in history capable of building up and retaining a separation of charge for later use. You'll find it quite shocking!

Materials: film canister
Aluminum foil
Small paper clip
Homemade electrophorus: Styrofoam pad
Pie pan with foam cup handle
Wool

1. Preparing the electrophorus. Carefully glue or velcro the upright empty cup in the center of the foil pie pan. This cup serves as the handle for the electrophorus and should be used at all times. To charge the pie pan, do the following: rub the foam pad vigorously with the scrap of wool, set the pie pan on top of the foam pad, touch your finger briefly to the outside rim of the pan, and then pick up the pan by its handle. Anything the pie pan is touched to will take on its excess charge.

2. Preparing the jar. Remove the lid from the film can and set it aside. Completely cover the outside of the can with foil, leaving about 1 cm around the top edge uncovered. Fill the inside of the can with water about 1 cm from the top. Replace the lid on the can.

3. Making the conductor. Unbend two loops of the paper clip and push it through the center of the top and into the water inside. Don't let it touch the sides or bottom of the can.

4. Revving it up. Using the homemade electrophorus, charge the pie plate. While holding the film can in one hand, touch the charged pie plate to the end of the paperclip that extends from the sealed canister. Repeat this step 2 or 3 times.

5. Setting it off. After you set the pie plate down the last time, touch the paper clip to your finger. What happens???

6. Taking a Stab. Now try to explain what happened at the atomic level to the electrons from start to finish from the foam pad to the wool, the pie plate, the paper clip, the inside of the jar, the tip of your finger.

How the Leyden Jar Works

The Leyden jar is a capacitor of a special physical construction. It bears the name Leyden for the town in which it was demonstrated. It consists of a jar or jar-like vessel coated inside and out with a conductive material. In the eighteen hundreds, these jars would be coated with tin, copper, or even gold foil. The one we have constructed is coated outside with aluminum foil and inside with water. Because it has two conductors separated by an insulator, it fits the classical definition of a capacitor.

When the negatively charged pie pan is touched to the paper clip, electrons are conducted into the film canister.

Because the plastic is an insulator, electrons cannot move through the plastic. The negative charges inside the canister, however, cause the molecules of the plastic to become polarized with their positive ends pointing toward the inside of the canister and their negative ends pointing toward the outside of the canister. This, in turn, causes electrons in the aluminum (which are free to move since aluminum is such a good conductor) to be repelled and move to the outer surface of the aluminum. When you touch the canister, these electrons flow into your hand, leaving the aluminum positively charged.

The presence of the positively charged aluminum foil coating enables a large number of electrons to be collected and stored inside the canister. Without the positive aluminum coating, electrons from the charged pie pan would only be transferred into the canister until something touches the paper clip and allows them to escape. This is exactly what happens when you (or other people) touch the paper clip.

If enough negative charge is stored in the Leyden jar, the electrons may escape from the paper clip to your hand when your hand is near, but not actually touching, the paper clip. If this occurs, you may see a visible spark as the electrons jump from the paper clip through the air gap to your hand. This is known as **spark discharge**.

Charges cannot be stored in your Leyden jar indefinitely because, even though air is an insulator, the electrons in the jar will gradually "leak" off the paper clip and onto any positively charged particles in the air.

Leyden Teacher Notes

Main idea: electric charges can be stored.

Duration: 20 min.

Student Background: students may know how to use an electrophorus to charge objects prior to this lab.

Advance Prep:

- Put together each electrophorus ahead of time if possible
- Collect enough 35-mm plastic film canisters for each group to make at least one jar.
- Velcro may work just as well as glue sticks to make the foam cup stick to the pie plate

Management Tips:

- Don't do this on a really damp or humid day. It won't work as well.
- To charge the pie plate, you must touch it while it is on the rubbed Styrofoam.
- You need to hold the canister in your hand when you touch the pie tin to the paper clip.

Desired Observations:

- Students should feel a mild shock (larger magnitude for more "charging").
- Students should see sparks.

Response to question: Because pie pan is positively charged, electrons from the paper clip are conducted to the pie pan. The paper clip, having thus lost some of its electrons, acquires a positive charge. The positive charge is stored in the Leyden jar. Because the plastic canister is an insulator, no electrons can enter the Leyden jar to neutralize this charge.

APPENDIX C2

Making a Light Bulb

The process of heated objects giving off light is called incandescence. The incandescent light bulb has been in use since Thomas Edison introduced the first practical version in 1879. In this activity, you will try to make a light bulb yourself.

Materials:

- wire for the filament (picture hanging wire or nichrome wire works best)
- a golf tee for forming the filament
- a source of electricity, such as a dry D-cell battery
- a clear baby food jar
- modeling clay
- wire for the connections

Procedure:

1. The filament: Take a piece of iron picture-hanging wire about 10 cm long. Unbraid it until you get a single strand of wire. Wrap the wire around a golf tee to form a coiled filament. Leave 2 cm of straight wire at each end.
2. The base: Flatten a piece of modeling clay big enough to cover the mouth of your jar. Stick the bare ends of your connecting wire through the clay. The wires should be just as far apart as the filament is long.
3. Finishing the bulb: Attach the filament to the wires by wrapping the filament wires around the connecting wires. Put the clear baby food jar over the filament wires and press it to the base. Check to be sure that the filament wire is still touching the connecting wire, and the connecting wires don't touch each other anyplace.
4. Connect your bulb to the battery: If it doesn't light by the count of ten, disconnect it and check your connections. Make sure the wires aren't touching under the clay.

Observations:

1. Which part of the light bulb gives out light?

2. Is there evidence of any other form of energy besides light coming from the light bulb? Explain.

3. Trace the energy flow from a dry cell to a flashlight bulb. Four forms of energy should be listed:

4. Why did our light bulbs burn out so much faster than commercial light bulbs do?

5. We have changed electricity to light. Is it possible to change light to electricity? Explain.

6. About how many years has the incandescent light bulb been in use?

Questions for Investigation and Discussion:

1. How does changing the length of the wire in the filament change the operation of the light bulb---for example, its brightness?

2. In our class, which group was able to make the longest-burning light bulb? Which feature(s) contributed most to its durability?

3. If you have an ohmmeter, ammeter, or multimeter, measure the current consumption of different homemade light bulbs operated from the same voltage source. What accounts for the variations in current consumption?

4. Besides the incandescent light bulb, how many other electric light sources can you find in use in your neighborhood? Make a map for your class showing the types of sources and where they can be seen.

APPENDIX C3

Making a Chemical Battery

Materials Provided:

- Wide-mouthed glass cup or jar
- 8-cm zinc strip
- 8-cm copper strip
- salt
- lemon juice
- water
- galvanometer

Procedure:

1. Pour water into the jar or cup until it is three fourths full.
2. Dissolve two teaspoons of salt in the water.
3. Tightly connect one end of your galvanometer to the copper strip and put it in the glass. Bend the zinc strip into a hook on one end and hang it inside the glass.
4. Wait a few seconds. Then observe the needle of the galvanometer as you firmly touch the other wire to the zinc strip.
5. What happened? Wait a few seconds, and then touch the wire to the zinc again.
6. Discuss your observations with your group.

Prelab Questions:

1. Why do you think the salt has to be in the water that goes in jar #1 for this lab? What is an electrolyte? (use a glossary or dictionary).

2. What are some properties of zinc and copper that would make them ideal for use in this experiment?

3. The measuring device used in this experiment is a galvanometer. What's a galvanometer made of? How does torque play a role in the functioning of a galvanometer? Read pages 505 and 506 of your text in order to have some background before answering below.

4. Step #4 in the procedure says to wait a few seconds before checking the galvanometer. Why the time lapse?

Now some problem solving: Try vinegar as the electrolyte instead of saltwater, and do the activity again. (Be sure to rinse the jar thoroughly whenever you change the electrolyte.) Try lemon juice. Replace the copper strip with the carbon rod. Try a penny in place of the copper strip, and a silver dime instead of the zinc (you'll have to find a dime that's several years old in order to get silver).

APPENDIX C4

Building a Real Electric Motor

This is the set of instructions for you to use today. You have 30 minutes in class to build your motor and answer the questions. If you can't get it to work, get help! In order to answer the questions correctly you truly have to experiment, so it's important to make the most of your time.

Because reversing an electric current in a DC motor or switching it on and off requires some sort of moving part, it makes sense to have the rotor (the only moving part) be an electromagnet. Such an electromagnetic rotor is called an armature. The field magnets, which are stationary, can be permanent magnets. It is important to note that while most commercial motors work because the direction of the current is reversed, our simple motor will turn the armature current on and off instead. We're going pretty basic here!

To make the armature for the motor, wind 6 turns of #22 enameled copper wire around a D-cell battery. Leave a tail several centimeters long at each end of the coil. Remove the coil from the battery and wind 2 turns of the tails around opposite sides of the coil, to hold it together.

Use steel wool to remove the enamel entirely from one of the tails. With the coil in a vertical position, remove the enamel from the **top half only** of the other tail. Center the tails and straighten them so they form a shaft for the armature coil.

To form supports for the armature, open 2 jumbo paper clips and bend a hook in the large end as shown. Use a sturdy rubber band or masking tape to attach one support to each end of a D-cell. Set a magnet on the cell. It will cling to the steel shell of the cell. This will serve as the field magnet of the motor.

To operate the motor, simply set the armature in the supports. Be sure that the armature is able to spin close to the field magnet without bumping into it. When the bare part of the half-sanded shaft spins and touches the support, current will pass through the armature coil, making it an electromagnet. The armature will either be attracted or repelled by the permanent field magnet. When the armature turns sufficiently, the enameled half of the shaft touches the support, shutting the current off; this, in turn, shuts off the magnetism of the armature. As the armature continues to coast around, the bare half of the shaft again touches the support, and the whole cycle repeats itself.

You may have to give the armature a gentle spin to get it started. Also, it might be necessary to roll the coil slightly forward to backward to find the optimal position for the armature to turn on and off. Changing the position of the field magnet might also improve performance. Holding a second magnet above the coil opposite the other one can result in increased speed.

Since this motor is so simple, it is possible to experiment with different magnets and different armatures of various sizes made of different numbers of turns of various gauges of wire.

Does reversing he armature in the supports affect the direction of spin? Why or why not?

Can you figure out a way to add a second cell to the motor?

Can you make an armature with 2 coils that intersect at right angles?

Experiment—do what the scientists do!

On your homemade electric motor the current is delivered to the armature by the paper clips; on commercial motors this is often accomplished by copper strips or carbon blocks called brushes (they brush against the armature).

Be aware that many industrial motors employ variations of the basic model such as making use of the secondary current generated within the motor itself, rotating the magnetic field of the stationary field magnets or using a permanent magnet rotor. You might run across such a motor in other investigations. Nevertheless, all of the electric motors operate on the principle of magnetic repulsion and attraction.

APPENDIX C5

Making a Cheapie Speaker

Background: In many ways a common speaker is like an electric motor. It uses magnetic attraction and repulsion to convert electrical energy to mechanical energy. Most ordinary speakers have both a permanent magnet and an electromagnetic coil, as do most small motors. But unlike the armature of a motor, which is designed to spin, the voice coil of a speaker is designed to move back and forth.

When a pulsating electric current passes through the voice coil, the strength of its magnetic field varies, so it interacts variably with the permanent magnet in a series of rapid pulses. To the voice coil is attached a flexible cone, often of paper, which serves to amplify the vibrations of the voice coil, thus making the sound louder. In other words, a speaker converts electrical pulses into mechanical vibrations which, in turn, produce sound waves in the air.

Other forms of speakers have an electromagnet around the voice coil instead of a permanent magnet. Still others use special crystals, which change size when an electric current is applied to them. Some speakers use electrostatic repulsion and attraction instead of magnetic.

Construction: Obtain some circular ceramic magnets about 2.5 cm in diameter. You'll also need a spool of enameled copper wire about 22 to 25 gauge; this is sometimes called magnet wire.

Wind a coil of about 50 turns of wire; the coil should have a diameter slightly larger than the magnet. The 2 ends of the wire protruding from the coil should each be about 20 cm long. Wind each end around the coil 2 or 3 times to keep the coil from unraveling. Use sandpaper to thoroughly remove the enamel coating from about 2 cm at the end of each wire. Fasten the coil to a plastic cup, as shown, using a rubber band of tape.

You will need a battery-powered radio with an earphone (not stereo) that can be lugged into it. Cut the earphone from its cord. Separate the two wires and make up the cord for a distance of a few centimeters. Carefully remove about 2 cm of the insulation from the end of each wire. For convenience you might wish to fasten a small alligator clip to each of the wires. Connect these wires to the wires from the coil. Be sure that you have tight connections.

Procedure: Turn on the radio and tune in a clear station. Plug your "cheapie speaker" into the radio, and turn up the volume. Hold the magnet in the center of the coil. You should be able to hear the radio playing faintly through your "cheapie speaker". Depending upon the power of the radio, you might have to hold your ear close to the cup.

Prelab Questions:

1. What effect would more coils of wire have on the speaker?

2. What effect would larger or smaller coils have on the speaker?

3. What does an amplifier do? (You may wish to use another source for information on amplifiers before answering.)

4. Is a speaker like a motor or like a generator? How so?

Further Investigation: The secret to success with this activity is experimenting. Try different magnets. Make various coils with different diameters and more or less turns. Try different kinds and sizes of cups. Will a metal can work? Vary the pressure with which you hold the magnet against the bottom of the cup. Fasten the coil to other objects. We have had great success with the coil fastened to a block of Styrofoam, a gallon plastic jug, the center of a poster board, even a tabletop!

APPENDIX D

RESOURCES

Bolemon, J. (1995). Physics. A Window on Our World. Englewood Cliffs, New Jersey. Prentice Hall.

Cunningham, J. (1994). Hands-on Physics Activities with Real-Life Applications: Easy To-Use Labs and Demonstrations for Grades 8-12. New York: Center for Applied Research in Education.

Guenther, A. (1997). Strengthening Your Teaching of Physical Science Concepts. Bureau of Educational Research.

Michigan State Board of Education. (1991). Michigan Essential Goals and Objectives for Science Education (K-12). Lansing, MI. Michigan Department of Education.

Texas Instruments. (1991). Exploring Physics and Math with the CBL System. New York. Texas Instruments.

Tolman, M. (1995). Hands-On Physical Science Activities for Grades K-8. New York: Parker Publishing Company, Incorporated.

Zitewitz, P. (1995). Merrill Physics. Principles and Problems. GLENCOE McGraw-Hill.

APPENDIX E

To: Parents/Guardians/Students
From: Miss Lindbeck (Hart High School Math/Science Dept.)
RE: Collection of Data for Master's Thesis

During the upcoming semester, one of the topics we will be studying in physics class is electricity. As part of my master's program through Michigan State University, I have designed a packet of labs and activities that is closely aligned with our text and curriculum. Students will be using everyday materials to model and analyze the behavior of electroscopes, batteries, motors, speakers, and other devices.

In order to evaluate the effectiveness of this unit, I will be collecting pretest data and surveys, homework, writing assignments, and posttest data and surveys. These items will be a required part of the course for all physics students. With your permission, I would also like to use this data in my master's thesis. Your child's participation is voluntary. He or she may discontinue participation in the surveys without penalty. At no time will any student's name be used in or connected to the thesis. Your privacy will be protected to the maximum extent allowable by the law.

Please fill out the section below and return to me as soon as possible. I am requesting permission to use data from student work and tests related to the electricity unit. There is no penalty for denying permission to use data. Any additional questions regarding rights as human subjects for research can be directed to Institutional Review Board chairperson David E. Wright at (517) 355-2181. Thank you for your time and cooperation.

Sincerely,

Amy L. Lindbeck

___I give Miss Lindbeck my permission to use my data from the electricity unit. I understand that she will not use my name and that all my student data will remain confidential.

______________________________ __________
Student Signature Date

______________________________ __________
Parent or Guardian Signature Date