Electrical Engineers

Grade Level: 4

Key Concepts
Relationships between Magnetism and Electrical Current * Faraday's Law

Mathematics Strands
Computation and Estimation * Measurement * Probability and Statistics

Skills
Conducting an Inquiry Investigation * Analyzing Data * Drawing Conclusions * Graphing

Nature of Science
Scientific Inquiry * Real-Life Applications * Error Analysis * Collaboration

Science	**Scientific investigation and exploration of the relationships between changing magnetic fields and electric current**
Technology	**Use of instrumentation to measure electric current and to demonstrate scientific principles**
Engineering	**Design and build experimental apparatus**
Mathematics	**Calculation of mathematic averages * Graphing**

Time:
Three 40-45 minute sessions

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Overview

Students will carry out a structured inquiry investigation of Faraday's Law of Induction, a physical law that states that the bigger the change in the magnetic field, the greater the voltage produced in a conducting coil. Students will observe Faraday's Law in action, by investigating the question: *How does the speed of a magnetic field moving through a copper wire coil affect the amount of electricity (moving charges- current) produced?*

Students will be directed through an investigation in which a strong magnet moves quickly through coiled copper wire to generate electricity. In the investigation, a strong ceramic magnet is attached to the top of a matchbox style car and released down an inclined track through a thick coil of copper wire. The resulting voltage is measured. Students will use a multimeter to collect voltage data (in millivolts) as a function of the release position of the magnet. The release position of the magnet on an inclined track will effectively control the speed of the toy car to which it is attached. Therefore, the voltage data will be collected as a function of the speed of the magnet, or as a function of the rate of change in the magnetic field as the car passes through the coil.

Students will create a graph of these data, analyze the data, and present their results and conclusions to the class. Students will also learn about Michael Faraday's contributions to the understanding of electricity.

Students will further explore induction through participation in online simulations.

Context

This investigation is a culmination activity clarifying and reinforcing the key concept of electromagnetic induction and would take place at or near the end of the electricity unit.

Before beginning this investigation, students should understand basic magnetic principles. They should already know:

- how a basic complete circuit looks, functions, and is properly assembled;
- what electrical current is and how it can flow along a copper wire or other electrical conductor to power an object;
- how a simple electromagnet is created;
- that a moving magnet in a coil can produce enough energy to power a multitude of devices;
- that a battery is the energy source of a one-bulb circuit; and
- that the battery causes the movement of the electrical charges along a wire.

Student will also need to know how to create a simple bar graph, find quantitative averages using a calculator, and round decimals to the nearest whole number.

Objectives

Know

- Electrical current can be created without a battery.
- A complete circuit is necessary for electricity to flow.
- A magnet has an associated magnetic field that exists beyond a physical magnet.
- Electricity can be generated by a changing magnetic field and a magnetic field can be observed around an electric current.
- Michael Faraday discovered induction of an electric current by a changing magnetic field. Faraday's Law says: *A constant magnetic field will not create voltage in a coil that is stationary*.

Understand

- Scientific investigation involves participating in processes such as questioning, experimenting, collecting data, analyzing data, drawing conclusions and sharing results.
- Induction is the physical phenomenon in which a changing magnetic field can be used to create an electric current.
- The movement of the magnet can result in a change of magnetic field at a specific location and will alter the amount of electricity created.

Do

- Conduct an investigation to identify the relationship between the change in a magnetic field and the amount of electricity produced.
- Design and construct an experimental set-up, including a complete circuit.
- Measure electrical voltage in millivolts (mV) using a Fluke® multimeter.
- Round decimals, calculate averages, and create bar graphs from experimental data.
- Analyze data and present results and conclusions regarding the relationship between a changing magnetic field and the amount of voltage produced.

Standards

Virginia Standards

Science 4.1 The student will demonstrate an understanding of scientific reasoning, logic, and the nature of science by planning and conducting investigations in which

c) appropriate instruments are selected and used to measure length, mass…in metric units;
d) appropriate instruments are selected and used to measure elapsed time;
e) predictions and inferences are made, and conclusions are drawn based on data from a variety of sources;
f) independent and dependent variables are identified;
g) constants in an experimental situation are identified;
h) hypotheses are developed as cause and effect relationships;
i) data are collected, recorded, analyzed, and displayed using bar…graphs;
j) numerical data that are contradictory or unusual in experimental results are recognized;
k) data are communicated with simple graphs, pictures, written statements, and numbers;

Science 4.3 The student will investigate and understand the characteristics of electricity. Key concepts include:

a) conductors and insulators;
b) basic circuits;
d) simple electromagnets and magnetism; and
e) historical contributions in understanding electricity.

Mathematics 4.4 The student will:

b) add, subtract, and multiply whole numbers;
c) divide whole numbers, finding quotients with and without remainders;
d) solve single-step and multistep addition, subtraction, and multiplication problems with whole numbers.

Mathematics 4.14 The student will collect, organize, display, and interpret data from a variety of graphs.

Mathematics 5.1 The student, given a decimal through thousandths, will round to the nearest whole number, tenth, or hundredth.

Mathematics 5.16c The student will find the mean…of a set of data.

Computer/Technology 3-5.7 The student will use technology resources for solving problems and making informed decisions.

National Standards

SCIENCE AS INQUIRY, Content Standard A (grades K-4 and grades 5-8)
As a result of activities in grades K-4, all students should develop

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE, Content Standard B (grades 5-8)
As a result of activities in grades 5-8, all students should develop an understanding of

- Properties and changes of properties of matter
- Motions and forces
- Transfer of energy.

SCIENCE AND TECHNOLOGY, Content Standard E (grades 5-8)
As a result of activities in grades 5-8, all students should develop

- Abilities of technical design
- Understandings about science and technology

HISTORY AND NATURE OF SCIENCE, Content Standard G (grades 5-8)
As a result of activities in grades 5-8, all students should develop understanding of

- Science as a human endeavor
- Nature of science
- History of science

Mathematics: Number and Operations Standard for Grades 3-5
In grades 3-5, all students should

- Understand the effects of multiplying and dividing whole numbers.
- Select appropriate methods and tools for computing with whole numbers from among mental computation, estimation, calculators, and paper and pencil according to the context and nature of the computation and use the selected method or tools.

Mathematics: Measurement Standard for Grades 3-5
In grades 3-5, all students should

- Understand the need for measuring with standard units and become familiar with standard units in the customary and metric systems;
- Select and apply appropriate standard units and tools to measure length, area, colume, weight, time, temperature, and the size of angles.

Mathematics: Data Analysis and Probability Standard for Grades 3-5
In grades 3-5, all students should

- Design investigations to address a question and consider how data-collection methods affect the nature of the data set;
- Collect data using observations, surveys, and experiments;
- Represent data using tables and graphs such as line plots, bar graphs, and line graphs

- Describe the shape and important features of a set of data and compare related data sets, with an emphasis on how the data are distributed;
- Use measures of center, focusing on the median, and understand what each does and does not indicate about the data set;
- Propose and justify conclusions and predictions that are based on data and design studies to further investigate the conclusions or predictions.

Mathematics: Communication Standard for Grades 3-5
Instructional programs from prekindergarten through grade 12 should enable all students to
- Organize and consolidate their mathematical thinking through communication;
- Communicate their mathematical thinking coherently and clearly to peers, teachers, and others

Preparation

Important Notes about Preparation

The preparation of the materials can be one way in which the teacher controls the level of inquiry in the investigation. Consider these options:

1. *Set up materials for students in advance. This structures the investigation and may be recommended to support students who would have difficulty with the engineering aspects of the investigation.*
2. *Guide students on how to assemble the investigative instruments. A guided inquiry approach makes the lesson more student-centered.*
3. *Have students engineer the experiment. By moving toward an open-inquiry approach, students have opportunities for problem solving, creativity, and decision-making. This is recommended for students who require more enrichment and/or less structure.*

What You Need

For the class (or teacher):

- ☐ Photos of investigation materials and set-up
- ☐ A computer with Internet access
- ☐ 2 Liter bottle or 4" diameter PVC pipe
- ☐ 1 copper coil loop with 280 turns
- ☐ Sandpaper
- ☐ *Inquiry Investigation Rubric*
- ☐ *Presentation Rubric*
- ☐ *Fluke Multimeter 115® Operation Guide*

For each group:

- ☐ 1 toy car (Matchbox® size)
- ☐ 3 plastic 12 inch long "Hot Wheels" Trick Track®-style connecting track
- ☐ 3 ceramic magnets: 1 7/8" x 3/8" x 7/8" each
- ☐ 1 "loop" of copper coil (approx. 160 feet of 22 gauge copper wire creating a continuous loop with 140 turns)
- ☐ 2 shoe boxes or something else to elevate to the height of 10 cm
- ☐ 1 meter stick
- ☐ 1 roll of masking tape
- ☐ 1 Multimeter (we used the *Fluke*® 115 model)
- ☐ 2 electrical alligator clips or simple circuit switches
- ☐ Sandpaper (if students are creating the circuit)
- ☐ Calculator
- ☐ *Fluke Multimeter 115® Operation Guide,* or similar for your instrument

For each student:

- ☐ *Pre-assessment and Post-Assessment*
- ☐ *Electrical Engineers Student Investigation Sheet*

An instructional kit of the implementation materials for this lesson, provided by a grant from the Toshiba Foundation, is available for loan from Sweet Briar College. For information, please contact:
Arlene Vinion-Dubiel
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434-381-6118

Getting Ready

Before the day of the activity

1. A week or two before implementing the lesson, give students the provided *Pre-lesson Assessment*. This will provide insight into students' understanding of electricity and magnetism and will guide you in how to assist in their instruction.
    a. Sample mini-lessons (*Basic Circuits*, *Magnets and Magnetic Fields, Electromagnets, Making a Bar Graph*) are provided in the Appendix. Teach these as indicated by pre-assessment results.
    b. Group students so that all members of a group begin at a similar level of conceptual understanding.

2. Gather teacher materials
    a. Internet access
        i. Watch and become familiar with the online simulation of Faraday's Law at: http://phet.colorado.edu/en/simulation/faradays-law
        ii. Find and have available the *Fluke*® 115 troubleshooting website in case of problems with the *Fluke*® Multimeter during the investigation: http://www.testequipmentdepot.com/fluke/pdf/115.pdf
        iii. Watch the video of *Electromagnetic Induction* (2:25) on BrainPop.com: http://www.brainpop.com/science/energy/electromagneticinduction (needs subscription)

3. Gather investigation materials

Set up the experimental apparatus

1. Prepare the copper coils. One copper coil will be needed for each investigation group.
    a. Wrap 22-gauge wire around a piece of 4" diameter PVC pipe (or a 2-liter soda bottle filled with water or air), by taping one end on the side of the pipe, leaving about 10" extended. Wrap with moderate tension for 140 continuous turns, leaving about 10" of extra wire at the end.
    b. Carefully remove the coil by sliding off all turns of the wire together, then tape the completed coil in three places to hold the coil turns together.
    c. Use sand paper to remove about 2" of the clear insulated coating on each end of the loose wire.

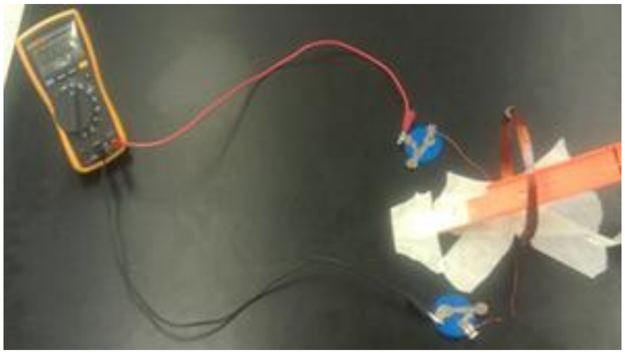
d. Make an additional coil of 280 turns for teacher demonstration purposes.

2. Assemble the magnet car. One magnet car will be needed for each investigation group.
   a. Attach the three (1 7/8 x 3/8 x 7.8) ceramic magnets to the top of the matchbox car, being sure not to apply tape over the car wheels. The magnet should be stacked so that the poles are facing the front and rear of the car, as seen in the picture. (The poles for this type of magnet exist on the faces as opposed to the long cylindrical magnets or bar magnets whose poles are on the ends.) This is to ensure that the poles of the magnet will enter the coil first. Make sure all tape is clear of tires and ramp surface.

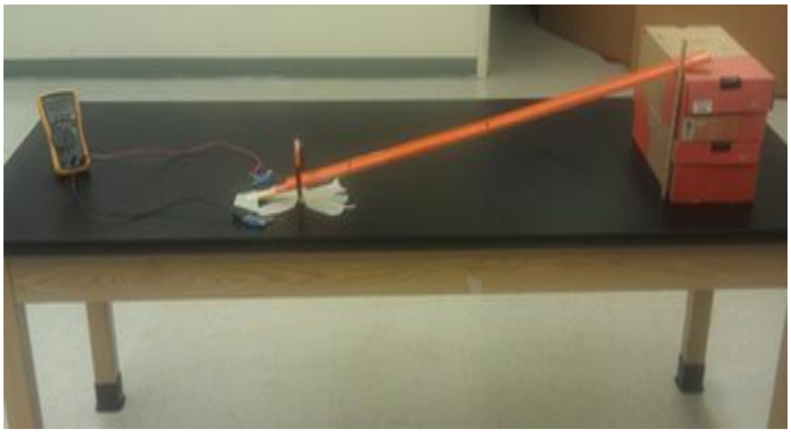
These strong magnets should be handled carefully to avoid pinching of the skin.

3. Assemble the ramp. One ramp will be needed for each investigation group.
   a. Attach 3 pieces of track together, and tape them to the meter stick so that the tape does not interfere with the surface or sides of the track.
   b. Mark the track at 20, 50, 100 cm from the bottom of the track with a permanent marker.
   c. Attach copper coil to a solid surface securely, as seen in the picture above. Leave the loose ends of the coil exposed for circuit connection
   d. Lay one end of the track through the copper coil, and secure the end of the track to the surface.
   e. Elevate the ramp to a height of about 20 cm (about the height of two stacked shoeboxes).

4. Assemble the circuit: 2 electric alligator clip wires will be needed for each investigation group.
    a. Attach electric alligator clip wires to the exposed ends of the coil wires and connect them to the two ends of the multimeter.
    b. Wires can be taped in place to avoid a break in the circuit.



The final apparatus is seen below:



Day One: Planning the Investigation

Engagement

1. **Introduce the question:** Write the inquiry question on the board and ask students to think about it: *How does the speed of a magnet moving through a copper wire coil affect the amount of electricity produced?*
    a. Allow students time to brainstorm and record their thoughts on a piece of paper or in their science journals.
    b. Students will share and discuss their thoughts with a partner or a small group.
    c. Discuss the question and students' thoughts as a class.
    d. Use this opportunity to identify any misconceptions and guide discussion or provide mini-lessons as needed.

Post the inquiry question on the board and keep it up for the rest of the lesson:
How does the speed of a magnet moving through a copper wire coil affect the amount of electricity produced?

Collect students' notes for later use at the conclusion of the investigation. These may also be used in formative assessment.

2. **Video demonstration:** After the discussion, show the Brain Pop online video, *Electromagnetic Induction* (2:25). Repeat and discuss the inquiry question.

http://www.brainpop.com/technology/energytechnology/electromagneticinduction

3. **Teacher demonstration** (*optional*): Demonstrate a preview of the investigation with your setup. Attach the multimeter to the ends of the copper wire with alligator clips, creating a closed circuit. Release the car (with magnets) down the ramp and through the coil.
    a. Set up the track and ramp, based on the section above, "Set up the experimental apparatus."
    b. Place the car with magnets at the top of the ramp, then release it, sending it down the ramp and through coil.
    c. You may have the voltage meter attached to the copper wires to show a quick sample of the data derived from the investigation, or you may choose to leave this part out.
    d. Guide students to identify the variables and constants:
        - Independent variable: height at which magnetic car is released
        - Dependent variable: amount of electricity produced; voltage level
        - Constants: car, track, copper wire of 140 turns, voltage meter, and meter measurement method

For an open-inquiry approach, consider not providing the procedure and/or lab sheet and allowing the students to design an experiment and/or data collection format on their own.

4. **Guide attention/discussion:** Hold a discussion to allow the students to generate their own predictions. Revisit the investigation question. Encourage students to support their predictions with reasoning and to use prior knowledge to support their understandings.

If allotted time for Day One is running short, you can end with the discussion after the teacher demonstration. If time remains, simply continue on to #1 and #2 of Day Two (see below).

Day Two: The Investigation

Introduce the Investigation

Investigation question:
How does the speed of a magnetic field moving through a copper wire coil affect the amount of electricity produced?

1. Hand out the *Student Investigation Sheet* (provided in appendix). Depending on your students' experience and facility with inquiry, you will need to discuss expectations and the parts of the investigation sheet with the students. Students who are comfortable with inquiry and have experience with conducting investigations may need little direct instruction. Students for whom inquiry is new and who have little experience with conducting investigations may need more guidance.

2. If students are using the terms "independent variable," "dependent variable", and "constant," reinforce this vocabulary in the context of this investigation. If students are not using these terms, elicit the vocabulary through questioning. If these terms were used earlier during the teacher demonstration, revisit them for clarification.

3. Discuss the relationship between release position and speed at the bottom of the ramp. Make sure the students understand that the higher up on the ramp the car starts, the faster it will be going by the time it enters the wire coil at the bottom.

4. Divide students into groups of 4. To help with investigation management and participation, designate student roles, see *Investigation Roles* handout (provided in appendix).

    - Leader
        - Makes sure group members are on task and getting along
        - Keeps track of the time allotted for the investigation
        - Makes sure the materials are used properly
    - Driver
        - Releases car from indicated positions on track
        - Makes sure to release (not push) the car, with the front of the car at each measured line
    - Meter Reader
        - Reads the multimeter results to the "Recorder"
        - Resets meter after each trial
    - Recorder
        - Records data (voltage as indicated by the multimeter)
        - Makes sure to share all results with the rest of the group if they are not recording them during the investigation

If groups of 5 are needed due to space, equipment, or other logistical reasons, a fifth role, the "Assistant" can be created. The Assistant should: reread directions to the group; make sure the procedure is being followed properly; and contact the teacher with any group needs or questions.

Conduct the Investigation

1. Students will assemble the investigation ramp and materials (car and circuit), following the "Procedure" section of the *Student Investigation Sheet* (provided in appendix) for detailed instructions.

2. Once setup is complete and you have checked to make sure it is working as expected, students will conduct the investigation and collect data. They will conduct three trials at each "release position," making sure to record data (Multimeter voltage readings) in the appropriate boxes on the *Student Investigation Sheet*.

3. During the investigation, walk around to monitor and informally assess student progress by filling in the *Inquiry Investigation Rubric* (provided in appendix) as you go. Use your notes for formative assessment of student understanding of electrical induction and scientific investigation. They will help you give feedback during the investigation and generate discussion at the conclusion of the day and/or the investigation.

The investigation materials may be preassembled to allow more time for instruction and assistance in large classes.

Data Analysis

1. Instruct or guide students in analyzing the data collected. Discuss (demonstrate as needed) taking an average of three trials. It may be necessary to take more than 3 trials. If this lesson is an introduction to averaging, explain it as finding the center among three measurements.

2. Students will compile their data into a bar graph showing the electrical voltage produced by changing the car's release position. Provide guidance and answer questions as needed.

If allotted Day Two time is running short, you may end the lesson at this point. If time remains, simply continue with Day Three's #1 and #2.

Day Three

Drawing Conclusions

1. Guide students as they formulate conclusions based on their findings, using their *Student Investigation Sheets.* Remind them of the initial investigation question, "How does the speed of a magnet moving through a copper wire coil affect the amount of electricity produced?"
   a. Students may complete the "Conclusion" portion of their *Student Investigation Sheets* individually, in their investigation groups, or as a whole class.

2. Once all students have completed the investigation, have analyzed the data, and have drawn conclusions, distribute the *Presentation Rubric* (provided in appendix). As a whole class, discuss the oral presentations and associated expectations. Key components of the presentations will be:
   a. Neat, organized, accurate presentation of **results**, through accurate and readable graphs as well as an oral summary
   b. Clear explanation of **conclusions**, based on using data as evidence
   c. Logical answer to the **investigation question**
   d. Ability to **answer questions** from teacher and peers

3. Using the rubric to plan, groups will prepare their class presentations.

4. If there is time, students will explore the PhET interactive simulations:
   a. "Faraday's Electromagnetic Lab" (http://phet.colorado.edu/en/simulation/faraday)
   b. "Faraday's Law" (http://phet.colorado.edu/en/simulation/faradays-law)

Keep investigation question posted:
How does the speed of a magnet moving through a copper wire coil affect the amount of electricity produced?

Day Four

Presenting and Sharing Results

1. Students will give their investigation presentations to the class.

2. To ensure concept understanding and mastery of skills pertinent to the investigation, ask questions. Sample interview questions include:
   a. Why was the copper wire coil an important item in the investigation?
   b. How would the removal of a magnet affect the results? What effect would this have on the amount of electricity produced?
   c. How would decreasing the number of turns in the copper coil affect the amount of electricity produced?
   d. If you could change one or two things in this investigation, what would they be and why?
   e. How does the magnet's magnetic field affect the copper wire?
   f. What role does speed play in the creation of electrical energy?
   g. How does the creation of this model help you to understand how electricity is created?
   h. Explain the following statement: *A magnetic field makes electricity and electricity makes a magnetic field.*
   i. How does electrical induction provide us with energy today?
   j. What questions do you still have about electrical induction?

3. After the presentations, discuss as a class any areas that require error analysis.

4. Address any misunderstandings related to electrical induction. To assist with misconceptions, see the "Going Further" extension activities.

5. Facilitate a culminating class discussion. Refer to the investigation question and to Faraday's Law. Clarify that understanding induction and the interaction between a magnetic field and a conductor is the key to understanding electromagnetic energy. Discuss the following questions:
   a. What contribution to the electrical world was Faraday most noted for?
   b. What important real-world objects function due to electrical induction?
   c. What are some important electrical concepts covered in our unit on electricity that were important in our study of electrical induction?

Administer the *Post-lesson Assessment* (provided in appendix).

Keep investigation question posted:
How does the speed of a magnet moving through a copper wire coil affect the amount of electricity produced?

Also consider handing out Presentation Interview Sample Questions *(provided in appendix) to students to answer and share orally when prompted.*

Use the results of the post-assessment to indicate which lesson objectives have been met successfully, and which need further work. Use the results of the post-assessment in comparison to the pre-assessment results to see where gains in understandings and skills have been made, by individual students as well as by the class overall.

Going Further

Taking the Law Personally

Students may write a personal definition of Faraday's Law, based on our investigation. Encourage students also to sketch a model of their investigation, making sure to label the parts: magnet track/ramp; 3 position markers; copper coil; and items in the closed circuit.

Online Simulations

If there was not enough time on Day Three, students can engage in the PhET simulations after the lesson. "Faraday's Law" and "Faraday's Electromagnetic Lab" students will be in charge of controlling and changing different variables to predict and learn about the relationship among variables and electricity generation. This can be done as a whole class activity or at individual or group stations, depending on time and technological accessibility.

a. "Faraday's Electromagnetic Lab" (http://phet.colorado.edu/en/simulation/faraday)

b. "Faraday's Law" (http://phet.colorado.edu/en/simulation/faradays-law)

c. "Generator" (http://phet.colorado.edu/en/simulation/generator)

Real-world applications

Students will do Internet research to find examples of induction in the real world. A good place to start might be the BrainPOP clip entitled "Energy Sources:"
http://www.brainpop.com/science/energy/energysources/

Poster Project

Students can create an "Electrical Induction Poster" to advertise Faraday's Law and his contributions to our knowledge of electricity.

Literature Connections

Books

(*grades 4-8*)

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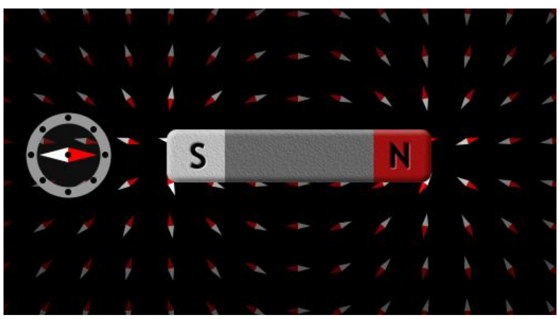
Behind the Scenes

Electricity and Magnetism

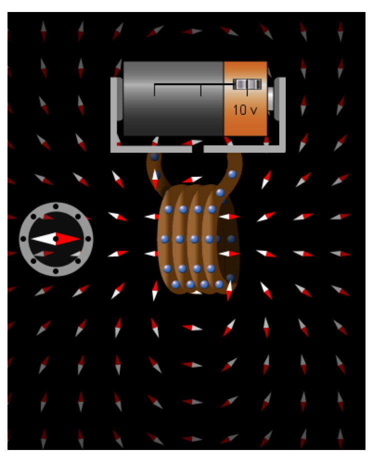
Electricity is a form of energy that we use every day, but few students have a good understanding of how it really works. This lesson uses the basic materials necessary for the creation of electricity (current) through magnetism in order to help students understand the origin of electricity.

A Danish chemist named Hans Ørsted and a British scientist named Michael Faraday made critical discoveries associated with electricity and magnetism. These two gentlemen shared their notes and theories involving electricity and magnetism to arrive at the understanding that a magnetic field is used to create electricity (also known as induction) and electricity is used to create a magnetic field (this is how electromagnets work).

Electric current is the continuous flow of negative charges (electrons). A *circuit* is the pathway followed by an electric current: a closed circuit allows electrical energy to move, while an open circuit prevents that movement.



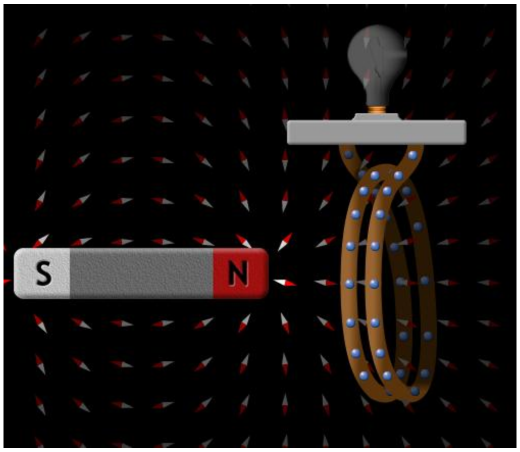
A *magnetic field* exists in space all around a magnet or electromagnet. The strength of the magnetic field gets smaller the further away from the magnet. This idea is best illustrated by playing with the PhET magnet simulation (Faraday's Electromagnetic Lab - bar magnet tab). In the simulation, the field can be visualized by the direction of the compass needles and their relative brightness (brighter needles show a stronger field), as seen in the screen capture here.



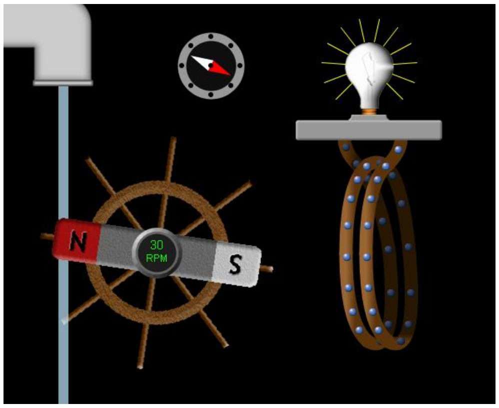
In order for the electrons in a conductor to flow through a circuit, a source of energy must be present too (via a battery or solar cell, or through induction).

The screen capture here shows the magnetic field created by current flow.

The creation of electric current by a changing magnetic field passing through a copper wire coil is known as *induction*. Teachers are encouraged to play with the PhET induction simulations in order to gain more experience with these ideas. The screen shot shows the PhET simulation where the user can "grab" the bar magnet and "push" it through the coil/bulb circuit to turn it on via induction. Because the strength of the magnetic field CHANGES in the coil as you move the magnet through the coil, a current is created in the coil. It is important to realize that there is NO BATTERY connected to the coil with the bulb.



This complex concept is the fundamental mechanism used in power generators, transformers, and power plants. Without Faraday's law of induction, our world would be very different! Large magnets and large electrical conductors rotate rapidly to create the electrical current we use. This idea is best understood by playing with the PhET Generator simulation, as shown in the screen capture below. This simulation allows you to rotate the bar magnet, which changes the magnetic field in the coil/bulb circuit. The idea here is the same as the previous simulation, though in this case the magnet rotates because of falling water. This simulation would be a good segue to a lesson on hydroelectric power.



In this activity, students will carry out an investigation using a copper wire coil, a ceramic magnet, a racecar, a race track, and a voltage meter in order to create a small amount of electrical current.

Lesson Sequence

Getting Ready:

1. Before Day One of the lesson, start collecting investigation materials.
2. Administer and score the *Pre-Assessment* and review the results to determine whether any of the *Mini-Lessons* are necessary.
3. Teach any necessary *Mini-Lessons*.

Day One:

1. Introduce investigation. Brainstorm with class and discuss the investigation question, *How does the speed of a magnet moving through a copper wire coil affect the amount of electricity produced?*
2. Show *BrainPop* clip, "Electromagnetic Induction" (http://www.brainpop.com/technology/energytechnology/electromagneticinduction).
3. Teacher demonstration (*optional*).
4. Distribute *Student Investigation Sheets* and discuss expectations.

Day Two:

1. Set up the experimental apparatus.
2. Assign or have students choose roles, using the handout *Investigation Roles*.
3. Conduct investigation and collect data.

Day Three:

1. Students will review and analyze data by creating a bar graph.
2. Students will draw conclusions based on data.
3. (*optional internet extension*) Simulations:
   a. Faraday's Law
      http://phet.colorado.edu/en/simulation/faradays-law
   b. Faraday's Electromagnet Lab
      http://phet.colorado.edu/en/simulation/faraday

Day Four:

1. Share findings via group presentations. Teacher will ask "Interview Questions" (*Presentation Interview Sample Questions*) and use the *Presentation Rubric* as a scoring guide.
2. Culminating class discussion.
3. (*optional*) Connect to real-world examples using demonstrations:
   a. PhET simulation, "Generator" at
      http://phet.colorado.edu/en/simulation/generator
   b. BrainPop "Energy" videos at
      http://www.brainpop.com/science/energy/
4. Administer, collect, and review the Post-Assessments

Assessment

Objectives

The overall learning objective of this lesson plan is for students to understand that a changing magnetic field can induce an electrical current (Faraday's Law of Induction). The motion of a magnet through a copper coil creates electrical voltage. The faster the magnet moves through the coil, the more voltage is created; the motion of the magnet is directly proportional to the amount of current created. Learning goals also include: understanding and creating a complete circuit; measuring voltage with a multimeter; making systematic observations; graphing and analyzing data to answer an investigation question; and practice with scientific processes through investigation (trials, variables, etc.) that lead to a deeper understanding of the nature of science.

Pre-lesson Assessment

The purpose of the pre-assessment is two-fold: to determine students' readiness for the lesson; and to establish a baseline of understanding that can be compared with the post-assessment to determine how well the lesson objectives were met. The pre-assessment will identify preconceptions and misconceptions about magnets, electrical circuits, electromagnetism, and induction. Pre-assessment results can be used to identify areas that need clarification or support lessons prior to the core lesson (see *Mini-Lessons One – Four*, provided), or students who need particular attention and guidance during and after the core lesson. Pre-assessment results can also be used to group students so that all in a group are at a similar level of understanding of electricity and magnetism.

Formative Assessments:

1. *Student Investigation Sheet*: Using this, students record and analyze data, then draw conclusions. Collect these at the close of the investigation to gain a sense of how much students have learned about induction.

2. *Presentation Interview Sample Questions* (to be asked on Day Four after the student presentations). The recommended questions will assist the teacher throughout the investigation in:
    - guiding students to an understanding of the key concepts within the lesson
    - identifying misconceptions about concepts related components of the investigation
    - connecting key concepts to practical applications in their community and world.

3. Anecdotal observations, as noted on the *Inquiry Investigation Rubric*, will generate qualitative data on the students' involvement, understanding of concepts, and data collection. The anecdotal record will also provide further insights as to any further instruction or direction that might be necessary.

Summative Assessments:

1. *Investigation Presentations*: Students share their findings and discuss the conclusions drawn based on the data. Their answers to the "interview" questions will provide further insights into their understanding of the concepts and mastery of the skills involved.

2. *Post-lesson Assessment*: is used to gauge students' mastery of the key lesson objectives. These results should be carefully analyzed to determine if further clarification of concepts is necessary.

Appendices: Handouts

1. Investigation Roles
2. Fluke Multimeter 115® Operation Guide
3. Pre-Assessment: Electrical Engineers
4. Mini-Lesson One: Basic Circuits
5. Mini-Lesson Two: Magnets and Magnetic Fields
6. Mini-Lesson Three: Electromagnets
7. Mini-Lesson Four: Making a Bar Graph
8. Teacher Investigation Guide
9. Electrical Engineers Student Investigation Sheet (4 pages)
10. Inquiry Investigation Rubric
11. Presentation Rubric
12. Presentation Interview Sample Questions
13. Post-Assessment: Electrical Engineers

Investigation Roles

<table>
<tr><td colspan="2">

Leader

Makes sure group members are on task and getting along; keeps track of the time allotted for investigation; makes sure the materials are used properly. If an "Assistant" is not included in the group, then the "Leader" will also be responsible for re-reading the procedure and contacting the teacher with any group needs or concerns.

What a good leader might sound like…

"We should talk about the investigation topic instead of other things"
"We need to keep an eye on the time, we want to be sure we finish our testing."
</td></tr>
<tr><td>

Driver

Releases car from indicated distances on track; must be sure to release (not push) with the front of car at each measured line.
</td><td>

Meter Reader

Reads Fluke Multimeter results to "Recorder"; resets meter after each trial.
</td></tr>
<tr><td>

Recorder

Records data (voltage as indicated by Fluke Multimeter); Makes sure to share all results with the rest of the group if they are not recording them during the actual investigation.
</td><td>

Assistant

Rereads directions to group; makes sure procedure is being followed properly. The assistant will also contact the teacher with any group needs, questions, or materials.
</td></tr>
</table>

Fluke Multimeter 115® Operation Guide

Operation Instructions

1. **Connect the red Fluke® Multimeter probe to the far right red hole labeled V.**
2. **Place the black Fluke Multimeter probe in the center black hole labeled com.**
3. **Turn the dial to mV symbol.**
4. **Press min/max button (second button from left, located just below digital screen). Make sure the digital screen reads "max" to ensure correct mode of min/max was selected.**
5. **To reset between tests/trials simply turn dial to V symbol and then back to mV symbol.**
6. **For remaining questions and a video usage clip visit the following website-http://www.testequipmentdepot.com/fluke/dmm/115.htm**
7. **For a troubleshooting guide visit the following website- http://assets.fluke.com/manuals/115C117Cumeng0100.pdf**

Pre-Assessment: Electrical Engineers   Name: __________________

1. A continuous flow of negative charges (electrons) creates a(n) ______________.

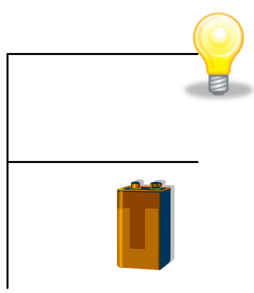
   a. proton
   b. solid mass
   c. electrical current
   d. loud noise

2. A complete path through which electricity flows is a(n) _______________.

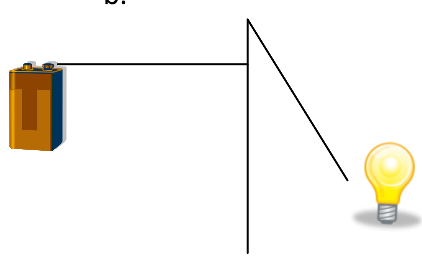
   f. circuit
   g. series
   h. cell
   j. fuse

3. Which of the following is an example of a working electrical circuit?

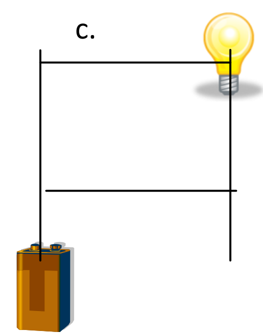
a.



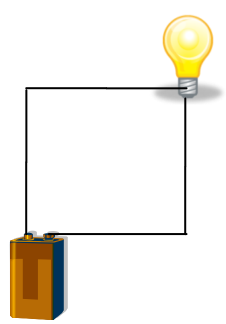
b.



c.



d.



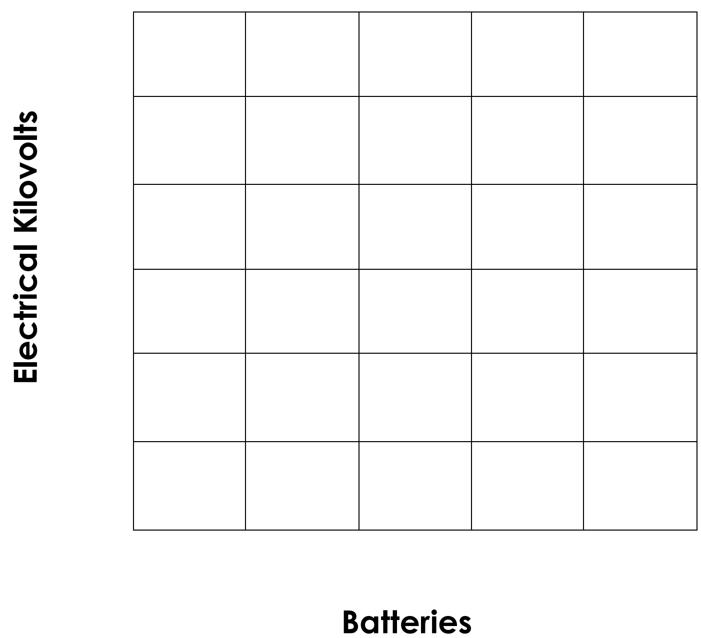
4. You have a light bulb and wire, but no battery. Can you make the bulb light up? If so, how and why? If not, why not?
____
____
____

5. Fill in the blanks.

An electric current creates a _________________________, and a _________________________ creates an electric current.
(Hint: both blank spaces should contain the same words.)

6. Joe is testing the voltage of his mini-batteries. He is testing five batteries. Create a bar graph for the data in the table.

Electrical Kilovolts	
Battery 1	35
Battery 2	14
Battery 3	42
Battery 4	50
Battery 5	26

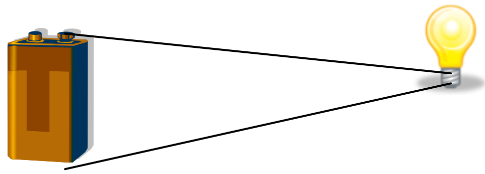


8. How do you feel about investigating magnets and electricity? Choose one.

- ☐ HELP!! I don't know anything about electricity and magnets.
- ☐ I know some things, and feel comfortable about learning more on this topic.
- ☐ I am an electrical whiz-kid. I am very confident with how much I know about electricity and magnets.

Predict which circuit will light up when assembled. Circle it. Test your predictions. Then, briefly explain why the circuit did or did not light up.

1.



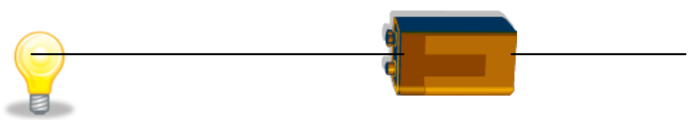
Explain: ______________________________________

____

____

____

2.



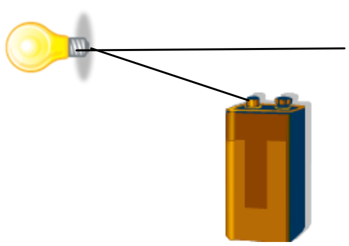
Explain: ______________________________________

____

____

____

3.

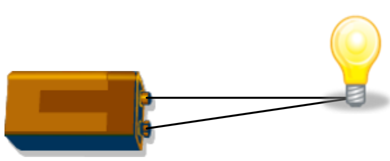


Explain: ______________________________________

____

____

4.

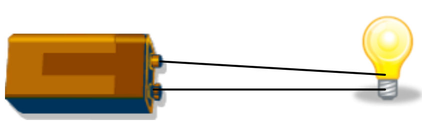


Explain: ______________________________________

____

____

5.



Explain:

____

____

____

____

Mini Lesson Two Magnets and Magnetic Fields

Below each magnet pair, write if they will attract or repel.

1.

____

2.

____

3.

____

4.

____

Using the magnet below, draw an example of its magnetic field. (remember: a magnetic field is the invisible area of force around a magnet.)

Mini Lesson Three Electromagnets

For this lesson you will need the following materials.
2 batteries, 12-15 inches of copper wire, 1 iron rod (or iron nail), metal paper clips

Draw a picture of a correctly assembled electromagnet in the box below. Be sure your electromagnet has the following materials labeled: nail, paper clips, copper wire, battery(ies).

Data
Test your electromagnet and fill in the data chart below.

Number Of Batteries (Cells)		Number of coils around iron rod (nail)	15	20	25	30
One						
Two						

Use your results in the table above to answer the following questions.

1. How many paper clips can be picked up using 15 coils and one cell?

2. How many paper clips were picked up using 25 coils and two cells?

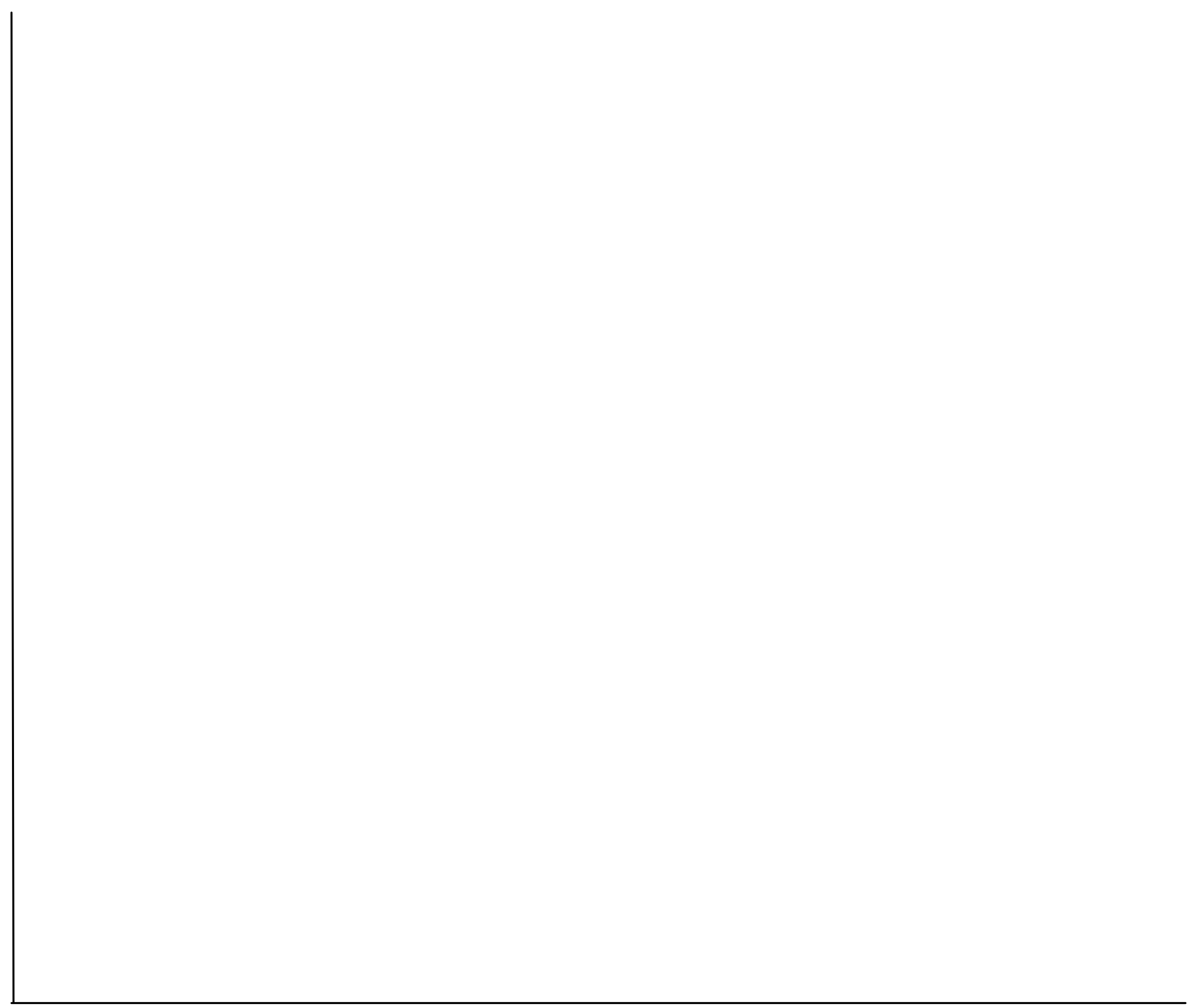
3. Did connecting more cells in the circuit affect the number of paper clips picked up?

4. What affects the number of paper clips that can be picked up?

Mini Lesson Four — Making a Bar Graph

Using the data table below make a correctly labeled bar graph.

Pet Store Sales	
Birds	23
Dogs	8
Cats	12
Fish	35
Hamsters	10



Electrical Engineers

Teacher Investigation Guide

Key Concepts

A moving magnetic field creates an electric current.

Related Concepts

-Basic Electrical Components (circuits)
-Magnetism
-Magnetic fields
-An electric current creates a magnetic field.
-Michael Faraday

Focus Question-

How does the speed of a magnetic field moving through a copper wire coil affect the amount of electricity produced?

Concept Skills-

Students will be able to:
Conducting an inquiry investigation, collect and analyze data,
analyze and/or engineer investigative tools, predict, measure electrical current, record, calculate averages, problem-solve, Use electrical Instruments, analyze effects of change in variables, and drawing conclusions.

Standards

Connections to State and National Standards (STEM)

Virginia Science SOLs

4.1 The student will demonstrate an understanding of scientific reasoning, logic, and the nature of science by planning and conducting investigations in which
c) appropriate instruments are selected and used to measure length, mass, volume, and temperature in metric units;
e) predictions and inferences are made, and conclusions are drawn based on data from a variety of sources;
h) hypotheses are developed as cause and effect relationships;
i) data are collected, recorded, analyzed, and displayed using bar and basic line graphs;
j) numerical data that are contradictory or unusual in experimental results are recognized;
k) data are communicated with simple graphs, pictures, written statements, and numbers; l) models are constructed to clarify explanations, demonstrate relationships, and solve needs.

4.3 The student will investigate and understand the characteristics of electricity. Key concepts include
a) conductors and insulators;
b) basic circuits.
e) simple electromagnets and magnetism; and
f) historical contributions in understanding electricity.

Virginia Math SOLs

4.4 The student will
b) add, subtract, and multiply whole numbers;
c) divide whole numbers, finding quotients with and without remainders; and
d) solve single-step and multistep addition, subtraction, and multiplication problems with whole numbers.

4.14 The student will collect, organize, display, and interpret data from a variety of graphs.

Virginia Computer/Technology SOLs

3-5.7 The student will use technology resources for solving problems and making informed decisions.

National Science Standards

Content Standard A - Science as Inquiry

As a result of activities in grades K-4, all students should develop
-Abilities necessary to do scientific inquiry
-Understanding about scientific inquiry

Content Standard B – Physical Science

As a result of activities in grades K-4, all students should develop an understanding of
-Light, heat, electricity, and magnetism

Materials

Each group will need the following set of materials

- 1 toy car (Matchbox® car size)
- 3 pieces of 12 inch long plastic racing track- Hot Wheels Trick Track®
- 3 ceramic magnets- 1 7/8" x 3/8" x 7/8" each

-1 "Loop" of copper coil- 22 gauge copper wire creating a loop with 140 turns (approx. 160 feet of wire)

-books or boxes equivalent to the height of 10 cm.

-1 meter stick

-1 roll of masking tape

-1 Multimeter (We used the *Fluke*® 115 model)

-2 electrical alligator clips or simple circuit switches

- sand paper

-calculator

-Electrical Engineers student investigation sheet

Background Information

(for instructor use only-not intended as a teaching tool)

The creation of electricity through magnetism is explored in this activity. Electricity is a common source of energy that we use, encounter and rely on in our daily lives. It can be a form of energy that is hard for students to understand. To assist in this difficult concept breaking it down to the basic creation and materials involved helps in understanding and connecting to real life scenarios.

Electric current is the continuous flow of negative charges (electrons). These negative charges are used to power many sources, such as light bulbs, motors, and many other electrical energy requiring objects. In order for these electrons to be pulled from the atoms they are connected to and around a circuit (or pathway) some sort of electromagnetic device must be present.

This creation of an electromagnetic device was hypothesized through the ideas of a Danish Chemist named Hans Orsted and a British Scientist, Michael Faraday. These two gentlemen combined their notes and theories of electricity and magnets to come up with the understanding that a magnetic field is used to create electricity and electricity is used to create magnetic field. The two gentlemen's concepts are what we know as electromagnetic induction- the creation of electric current by a magnetic field passing through a copper wire coil,

It is easiest to explain and relate this complex concept to the use of power generators, transformers, and power plants. If large magnets and large electrical conductors are not rapidly crossing paths in a continuous motion then electrical current would possibly never exist. In this activity, by the use of a copper wire coil (140 loops thick), ceramic magnet, race car, race track, and a multimeter students will build an investigation to create a small amount of electrical current by having a magnet's magnetic field and an electrical conductor (copper wire coil) interact. They are then challenged to establish the connection of this concept to real world events, by extending the activity through various questions, simulators, and activities.

Management

1. This activity should be done as unit conclusion. So that all areas of electrical study have been covered and students are able to make the multiple connections of electrical study seen in this investigation.
2. The activity is designed to be structured or teacher guided in inquiry, but easily adaptable to becoming more student guided or even open if the teacher feels students are capable of such.
3. Students should be encouraged to develop questions and connections on their own throughout the investigation as well as the importance of the data being recorded.

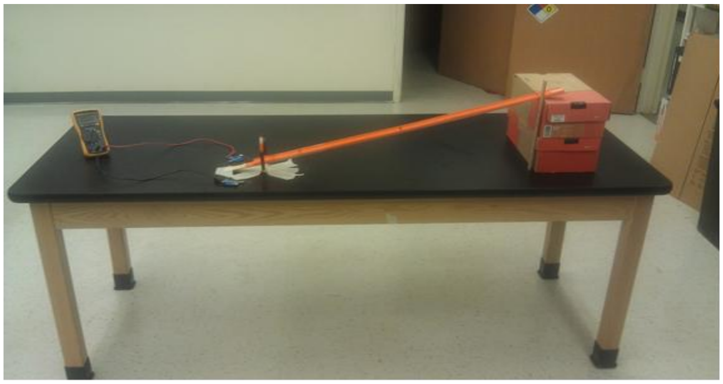
Lab Assistance Notes

Ramp

1. Piece together 3 pieces of 12 inch long plastic racing track- Hot Wheels Trick Track®
2. Using the meter stick; measure and mark on the track a 20 centimeter line, 50 centimeter line, and an 100 centimeter line. (These will be your three different release points for your car.)
3. To support track, tape bottom of track to meter stick, starting from top of track down. Be sure that tape does not extend onto track surface.
4. Place one shoe box at one end of the track. Lay track off the shoe boxes creating a ramp. Use masking tape to attach track with meter stick end to edge of shoebox top. (Your ramp should be about 10 centimeters high).

5. Securely tape down wire coil ring to the table using masking tape. Then lay the track through wire coil and tape down ramp end to the table.
6. Using alligator clips or circuit switch clips, attach one clip to exposed end of coiled wire and the other end to the multimeter probe. Repeat with the other wire end and probe.

Teacher Procedure/Outline



Before Lesson-

1. Be sure to administer pre-assessment (handout: pre-assessment) a week or two before investigation. This will provide insight to student's electrical and magnetic understanding and guide you in where to assist in their instruction. Sample mini lessons are provided to assist in students' area of need. (handout section)
2. Preassemble the following materials-
-copper wire coils of 140 loops each
-Ramps if students are not building the model themselves.

Day One-

1. Write inquiry question on the board and ask students to think about inquiry question: "How does the speed of a magnet moving through a copper wire coil affect the amount of energy produced?"
2. Show students the Brain Pop online video selection: "Electrical Induction" (2:25) www.brainpop.com upon completion of online video, repeat inquiry question: "How does the speed of a magnet moving through a copper wire coil affect the amount of energy produced?"
3. Demonstrate a single trial of the investigation Ask students how they think it could answer the inquiry question. Guide students to identify constants (magnet, copper hoop with 140 coils), and independent variables (speed = distance of magnet from wire coil on the inclined track) and dependent variables (voltage level).
4. Hand out Student Investigation Sheet (handout: student investigation sheet) and go over problem and hypothesis for the investigation. Complete alone or as a class depending on students level of inquiry instruction.
5. Teacher will also note observations of student involvement by writing anecdotal assessments on chart (handout: Inquiry Lab Rubric).
6. Answer questions.

Day Two-

1. Assemble model based on lab sheet procedure. Assist students with model creation or allow them to perform alone based on inquiry ability. *(This may be done prior to todays agenda)*
2. Designate jobs for each group member. The following positions are needed: (you may choose your job or draw cards from a bag to make it fair.)
   a) Leader-makes sure group and group members are on task, being considerate of the time allotted for investigation, getting along, and testing the material properly. If an "Assistant" is not assigned to the group, then the "Leader" will also be responsible for re-reading the procedure and contacting the teacher with any group needs or concerns.
   b) Driver- releases car from indicated distances on track. Must be sure to release (not push) with the front of car at each measured line.
   c) Meter Reader-reads Fluke Multimeter results to "Recorder" and resets meter after each trial.
   d) Recorder- records data (voltage as indicated by Fluke Multimeter) and makes sure to share all results with the group if group is not recording during the actual investigation.
   e) Assistant-will re- read directions to group and makes sure procedure is being followed properly. The assistant will also contact the

teacher for any group needs, questions, or materials.

3. Test and collect data on investigation.
4. Answer questions.

Day Three-

1. Review and analyze student data, complete graph.
2. Discuss and formulate conclusions based on data.
3. Use PhET-Interactive Simulations www.Phet.colorado.edu - Faradays Law and Faradays Electromagnetic Lab
4. Answer questions.

Day Four-

1. Groups present their results and discuss electricity unit connections as well as real world connections. Teach completes a rubric for each oral presentation, (Handout: Inquiry Presentation Rubric).
2. Share the following two activities to assist and guide in connection discussions-
    a. PhET Interactive Simulation- Generator
    b. BrainPOP Clip- Energy. (This clip does extend into other forms of energy i.e. solar, nuclear, but also provides a great electrical energy section.)
3. Extend by using extension activities provided.
4. Answer questions and wrap up investigation.

Optional Extension Activities (can be used during or after lesson completion; time permitting)

1. Students may write a personal definition of Faraday's Law based on our investigation. Encourage students to also sketch a model of their investigation making sure to label the key parts: magnet track/ramp, three distance markers, copper coil, and items in the closed circuit.

2. Have students participate in an electromagnet simulation. Through the PhET website http://phet.colorado.edu under the simulators- "Faraday's Law" and "Faradays Electromagnetic Lab" students will be in charge of controlling and changing different variables to predict and learn about the relationship among the variables to electricity generation. This can be done as a whole group activity or done at individual stations depending on time and technology accessibility.

3. For a real-world connection involving electromagnetic induction students can visit the BrainPOP website at www.brainpop.com to view the BrainPOP clip entitled "Energy Generating Electricity"

4. For a real-world connection involving electromagnetic induction students may visit the PhET Interactive Simulation site at www.phet.colorado.edu and manipulate the simulator called "Faradays Electromagnetic Lab- Generator" for even more concept connections.

5. Students can create a "Electrical Induction Poster" advertising Faradays law and electrical contribution to the scientific world.

Connecting Focus Questions(Interview Questions)

1. How does the magnets magnetic field affect the copper wire?
2. How does speed play a factor in the creation of electrical energy?
3. How does the creation of this model help you to understand the way electricity is created?
4. Explain the following statement- a magnetic field makes electricity and electricity makes a magnetic field.
5. How does electrical induction provide us with electrical energy today?
6. What questions do you still have about electrical induction?

Fluke Multimeter Operation DIrections

1. Connect the red Fluke Multimeter probe to the far right red hole labeled V. Then place the black Fluke Multimeter probe in the center black hole labeled com.
2. To operate be sure to turn dial to mV symbol.
3. Press min/max button second button from left, located just below digital screen. (Be sure the digital screen reads max on the top to ensure correct mode of min/max was selected.)
3.To reset between tests simply turn dial to symbol and then back to mV symbol.
4. Troubleshooting website for Fluke 115
http://www.testequipmentdepot.com/fluke/pdf/115.pdf

Electrical Engineers

Name: ___________________________

Student Investigation Sheet

Problem- How does the speed of a magnetic field moving through a copper wire coil affect the amount of electricity produced?

Hypothesis-

If____

____.

Then____

____.

Materials-

- 2 alligator clips
- 3 ceramic magnets
- 1 copper wire coil (pre-coiled 140 times)
- 1 shoe box or objects equivalent to 30cm in height
- Masking tape
- 1 Fluke 115® Voltage Meter
- Meter stick
- 3 pieces of 12 inch Hot Wheels Trick Track®
- toy car (Matchbox® size)

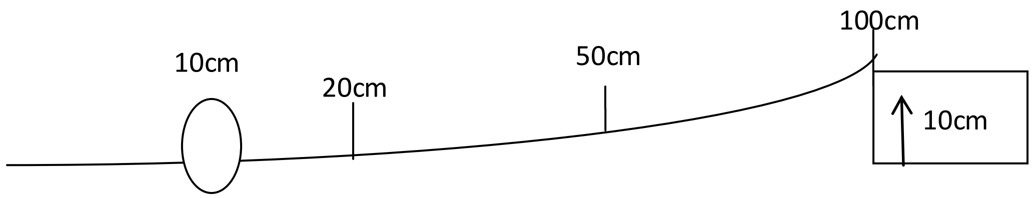
Procedure-

1. Gather all materials

2. Construct ramp using the following instructions and picture to assist you.

   a. Connect Hot Wheels Trick Track together.
   b. Using the meter stick, measure from the end of the track and mark a line on the track at 10 centimeters, 20 centimeters, 50 centimeters, and 100 centimeters. The marks indicate three different release points for your car and the coil position. Label the marks as shown: The 10 centimeter line is where you will place the coil of wire. Label it as "Coil." The 20 centimeter line is your Low release point. Label it as "Low." The 50 centimeter line is your Medium release point. Label it as "Medium." And your 100 centimeter line is your High point. Label it as "High."
   c. To support track, tape bottom of track to meter stick, starting from top of track down. Be sure that tape does not extend onto track surface.
   d. Stack two shoes boxes one on top of the other. Lay track off the shoe boxes creating a ramp. Use masking tape to attach track with meter stick end to edge of shoebox top. (Your ramp should be about 30 centimeters high).

e. At the “Coil” mark, securely tape down wire coil ring to the table using masking tape. Then lay the track through the wire coil and tape the end of the ramp down to the table.



f. Using alligator clips or circuit switch clips, connect the exposed ends of coiled wire to the leads of the multimeter.

3. Once the ramp is constructed, designate jobs for each group member as instructed by your teacher. The job duties are described on the *Investigation Roles* handout.

4. For EACH release position, Low, Medium, and High, your team will conduct (at least) THREE trials. In each trial, the Driver will release (not push) the magnet-car down the ramp. The Meter-Reader will read the voltage produced in millivolts, as measured by the multimeter. The Recorder will record this reading and share with all team members. For additional information on using the multimeter see handout **Fluke Multimeter 115® Operation Guide.**

5. All group members need to record data in the Data section and complete the conclusion questions on his/her own Student Investigation Sheet.

Data-

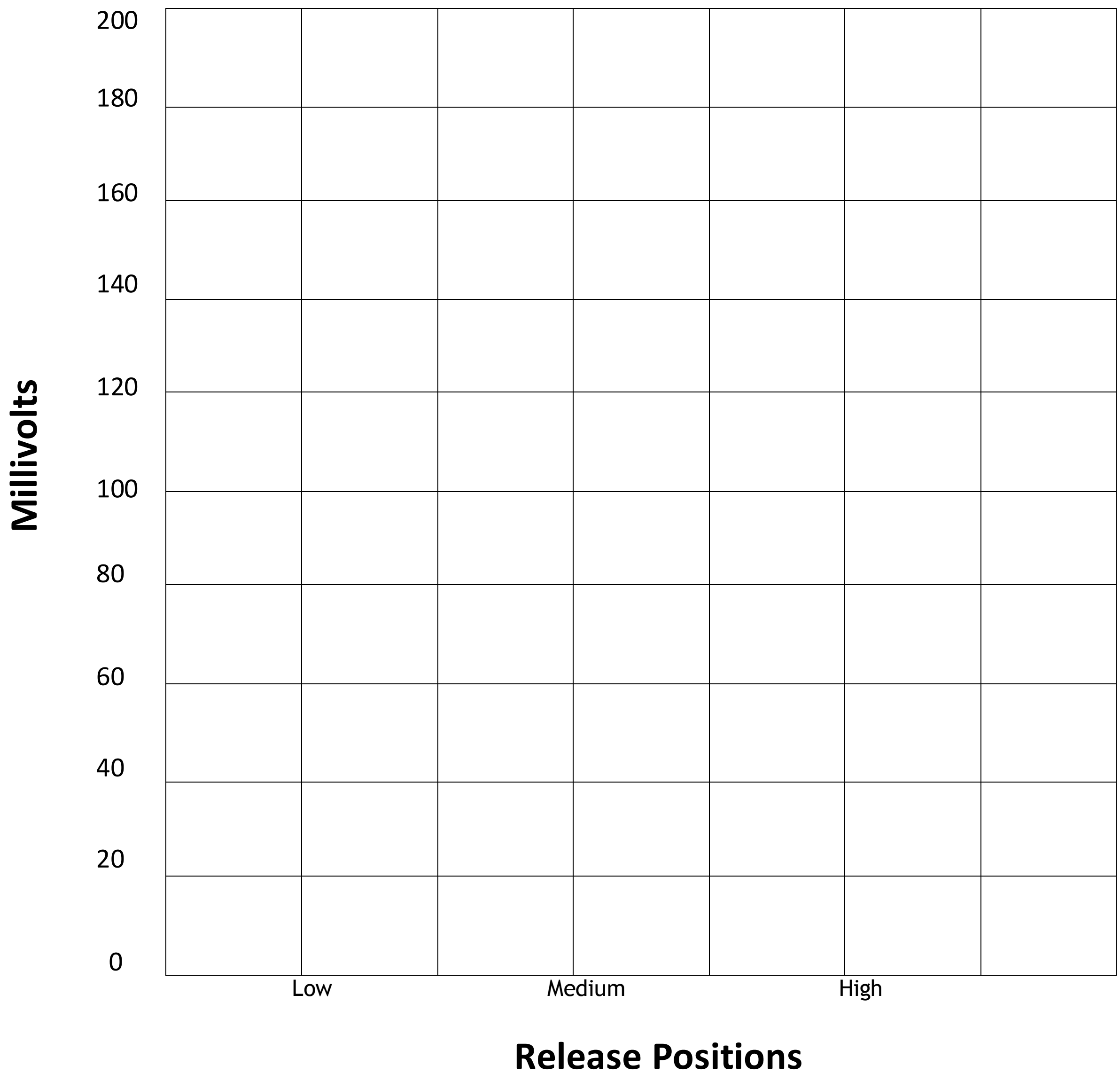
Sum the voltage generated from your three trials and divide by three. Round this number to the nearest whole number.

	Voltage generated from Low position	**Voltage generated from Medium position**	**Voltage generated from High position**
Trial One			
Trial Two			
Trial Three			
Sum of each height (total number when you add up all 3 trials)			
	Divide by 3	Divide by 3	Divide by 3
Average Voltage	mV	mV	mV

Analyze your Data-

Using your results you recorded in the data table complete the bar graph below.

Electricity Generated



Conclusion-

With your group members, discuss and answer the following questions.

1. In your own words, describe what happens when we send a magnet down a ramp and through a coil of wire.

____

____

____

____

____.

2. Based on your experimental data, which “release position” produced the most electricity? Why do you think this happened?

____

____

____

____.

3. What is the relationship between the speed of the magnet and the amount of electricity that is produced?

____

____

____

____.

4. Explain the following statement- a magnetic field creates electricity and electricity creates a magnetic field.

____

____

____

____.

Inquiry Investigation Rubric

	Student Name	**On Task**	**Model Accurately Constructed**	**Data Collected**	**Demonstrates Understanding of Key Concept**	**Comments** Student Discoveries, Challenges, Observations
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						

Presentation Rubric

Students in Group	

3	2	1
Excellent	**Good**	**Needs Improvement**

Score	A. Analyzes Data
	All results are clearly and neatly presented in the table.
	Units of measurement are listed. (mV for millivolt)
	All math is correct.
	Results are represented correctly in a graph.
	Graph is neatly completed and easy to read.
	A SUMMARY of the results are presented to peers in the oral presentation. (Results are not read from table, but summarized in presentation.)

Score	B. Draws Conclusions
	Conclusion questions are clearly answered with complete sentences on conclusion sheet.
	Data is used to answer conclusion questions. Results are connected with conclusions.
	Conclusions are communicated clearly to peers in oral presentation.

Check When Complete	C. Answers Investigation Question
	Investigation question is clearly answered.
	Group explains HOW their results answer the investigation question.
	Group is able to answer questions by their peers correctly using their data.
	Group Total Score

Teacher Comments:

Presentation Interview Sample Questions

(Teacher may ask questions during presentation or hand out the questions for students to answer and share orally when prompted; teachers choice)

1. How does the magnet's magnetic field affect the copper wire?

2. What role does speed play in the creation of electrical energy?

3. How does the creation of this model help you to understand the way electricity is created?

4. Explain the following statement: *A magnetic field makes electricity and electricity makes a magnetic field*.

5. How does electrical induction provide us with energy today?

6. What questions do you still have about electrical induction?

7. Why was the copper wire coil an important item in the investigation?

8. How would the removal of a magnet affect the results? What effect would this have on the amount of electricity produced?

9. How would decreasing the number of turns in the copper coil affect the amount of electricity produced?

10. If you could change one or two things in this investigation, what would they be and why?

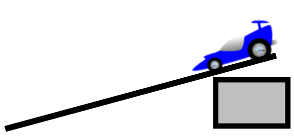
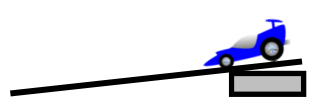
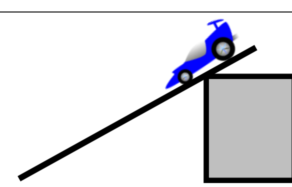
Post-Assessment: Electrical Engineers Name: ____________

1. What is a complete path through which electricity flows called?
____
____

2. What does a continuous flow of negative charges (electrons) create?
____
____

3. How is electricity created by moving a magnetic field through a coil of copper wire?
   a) Electricity cannot be created this way.
   b) The magnetic field pushes the electrons in the wire into motion, creating electricity.
   c) A battery must be hooked to the magnet to create electricity.
   d) Electrons jump from the magnetic field into the copper wire.

4. Look at the three ramps. If you put the “magnet car” on each of the three ramps, which would you predict would create the biggest electrical current, and why? Assume that the coil of wire is at the bottom of the ramp though it is not included in the sketches.

		
ramp 1	ramp 2	ramp 3

____

____

____

5. How are the principles we discovered in this investigation used in the real world? Give one example. ____

____

____

____

6. Sandra has conducted an investigation to answer the question, "Will the amount of turns (loops) of copper wire in the coil affect the amount of voltage that a magnetic field can create?" The results of her investigation are listed in the table below. Create a bar graph with Sandra's data. Round each voltage to the nearest whole number. (Example: 1.7 volts would round to 2 volts.)

Turn Investigation	
100 turns	1.3 volts
125 turns	1.8 volts
150 turns	2.1 volts
175 turns	2.6 volts
200 turns	3.8 volts

Turn Investigation

7. Fill in the blanks.

An electric current creates a _________________________, and a

__________________________ creates an electric current.

8. How do you feel about investigating magnets and electricity after completing the investigation? Choose one

- ☐ Electricity has fried my brain!! I more confused than ever!
- ☐ I have learned a lot about electricity and magnets, but I still have some questions.
- ☐ I'm ready to start my career in electrical engineering!

Pre-Assessment: Electrical Engineers   Name: ___________________

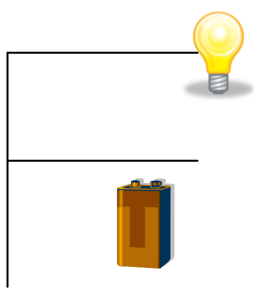
1. A continuous flow of negative charges (electrons) creates a(n) _______________.

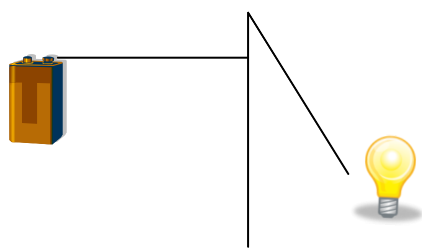
   a. proton
   b. solid mass
   c. electrical current
   d. loud noise

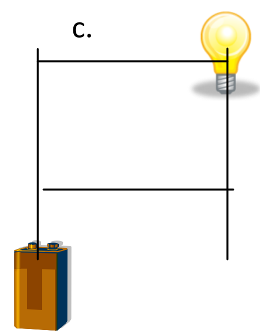
2. A complete path through which electricity flows is a(n) ________________.

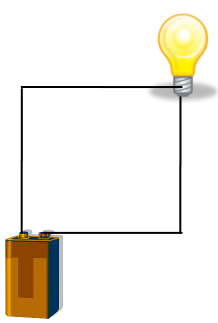
   f. circuit
   g. series
   h. cell
   j. fuse

3. Which of the following is an example of a working electrical circuit?

a.


b.


c.


d.


4. You have a light bulb and wire, but no battery. Can you make the bulb light up? If so, how and why? If not, why not?

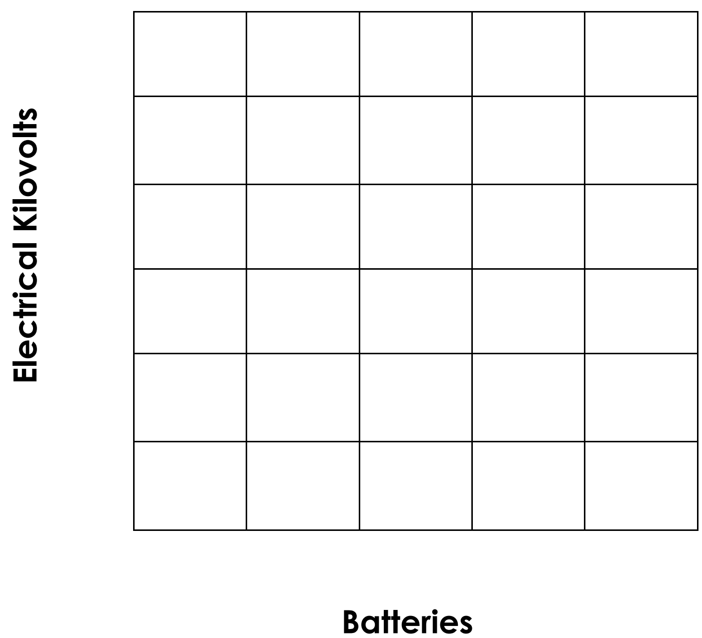
____
____
____

5. Fill in the blanks.

An electric current creates a _________________________, and a __________________________ creates an electric current.
(Hint: both blank spaces should contain the same words.)

6. Joe is testing the voltage of his mini-batteries. He is testing five batteries. Create a bar graph for the data in the table.

Electrical Kilovolts	
Battery 1	35
Battery 2	14
Battery 3	42
Battery 4	50
Battery 5	26



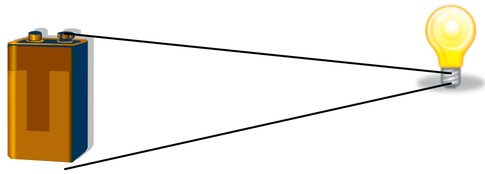
8. How do you feel about investigating magnets and electricity? Choose one.

- ☐ HELP!! I don't know anything about electricity and magnets.
- ☐ I know some things, and feel comfortable about learning more on this topic.
- ☐ I am an electrical whiz-kid. I am very confident with how much I know about electricity and magnets.

Mini Lesson One **Basic Circuits**

Predict which circuit will light up when assembled. Circle it. Test your predictions. Then, briefly explain why the circuit did or did not light up.

1.



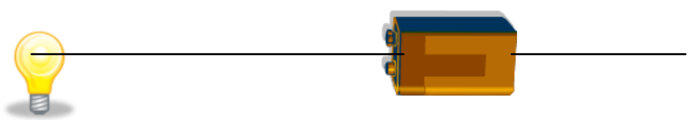
Explain: ____

____

____

____

2.



Explain: ____

____

____

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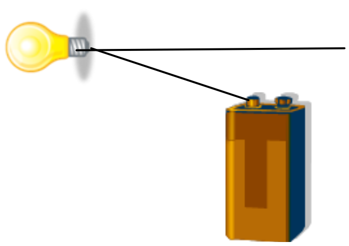
3.

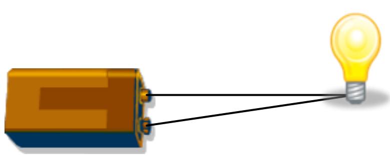


Explain: ____

____

____

4.

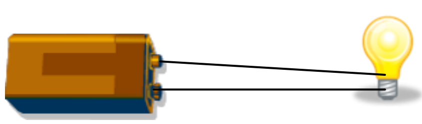


Explain: ____

____

____

5.



Explain:

____

____

____

____

Mini Lesson Two **Magnets and Magnetic Fields**

Below each magnet pair, write if they will attract or repel.

1.

____

2.

____

3.

____

4.

____

Using the magnet below, draw an example of its magnetic field. (remember: a magnetic field is the invisible area of force around a magnet.)

Mini Lesson Three **Electromagnets**

For this lesson you will need the following materials.
2 batteries, 12-15 inches of copper wire, 1 iron rod (or iron nail), metal paper clips

Draw a picture of a correctly assembled electromagnet in the box below. Be sure your electromagnet has the following materials labeled: nail, paper clips, copper wire, battery(ies).

Data
Test your electromagnet and fill in the data chart below.

Number Of Batteries (Cells)		Number of coils around iron rod (nail)	15	20	25	30
One						
Two						

Use your results in the table above to answer the following questions.

1. How many paper clips can be picked up using 15 coils and one cell?

2. How many paper clips were picked up using 25 coils and two cells?

3. Did connecting more cells in the circuit affect the number of paper clips picked up?

4. What affects the number of paper clips that can be picked up?

Mini Lesson Four **Making a Bar Graph**

Using the data table below make a correctly labeled bar graph.

Pet Store Sales	
Birds	23
Dogs	8
Cats	12
Fish	35
Hamsters	10

Electrical Engineers

Name: ______________________________

Student Investigation Sheet

Problem- How does the speed of a magnetic field moving through a copper wire coil affect the amount of electricity produced?

Hypothesis-

If____

____.

Then____

____.

Materials-

- 2 alligator clips
- 3 ceramic magnets
- 1 copper wire coil (pre-coiled 140 times)
- 1 shoe box or objects equivalent to 30cm in height
- Masking tape
- 1 Fluke 115® Voltage Meter
- Meter stick
- 3 pieces of 12 inch Hot Wheels Trick Track®
- toy car (Matchbox® size)

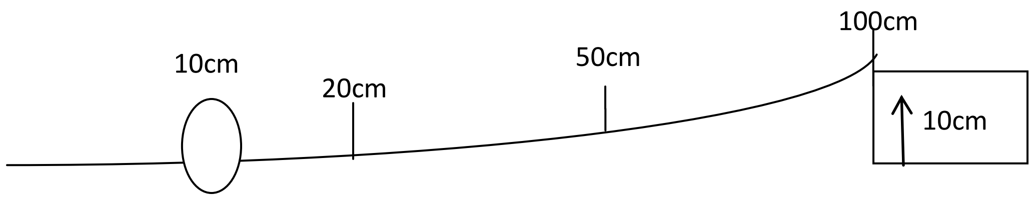
Procedure-

1. Gather all materials

2. Construct ramp using the following instructions and picture to assist you.

    a. Connect Hot Wheels Trick Track together.
    b. Using the meter stick, measure from the end of the track and mark a line on the track at 10 centimeters, 20 centimeters, 50 centimeters, and 100 centimeters. The marks indicate three different release points for your car and the coil position. Label the marks as shown: The 10 centimeter line is where you will place the coil of wire. Label it as "Coil." The 20 centimeter line is your Low release point. Label it as "Low." The 50 centimeter line is your Medium release point. Label it as "Medium." And your 100 centimeter line is your High point. Label it as "High."
    c. To support track, tape bottom of track to meter stick, starting from top of track down. Be sure that tape does not extend onto track surface.
    d. Stack two shoes boxes one on top of the other. Lay track off the shoe boxes creating a ramp. Use masking tape to attach track with meter stick end to edge of shoebox top. (Your ramp should be about 30 centimeters high).

e. At the “Coil” mark, securely tape down wire coil ring to the table using masking tape. Then lay the track through the wire coil and tape the end of the ramp down to the table.



f. Using alligator clips or circuit switch clips, connect the exposed ends of coiled wire to the leads of the multimeter.

3. Once the ramp is constructed, designate jobs for each group member as instructed by your teacher. The job duties are described on the *Investigation Roles* handout.

4. For EACH release position, Low, Medium, and High, your team will conduct (at least) THREE trials. In each trial, the Driver will release (not push) the magnet-car down the ramp. The Meter-Reader will read the voltage produced in millivolts, as measured by the multimeter. The Recorder will record this reading and share with all team members. For additional information on using the multimeter see handout **Fluke Multimeter 115® Operation Guide.**

5. All group members need to record data in the Data section and complete the conclusion questions on his/her own Student Investigation Sheet.

Data-

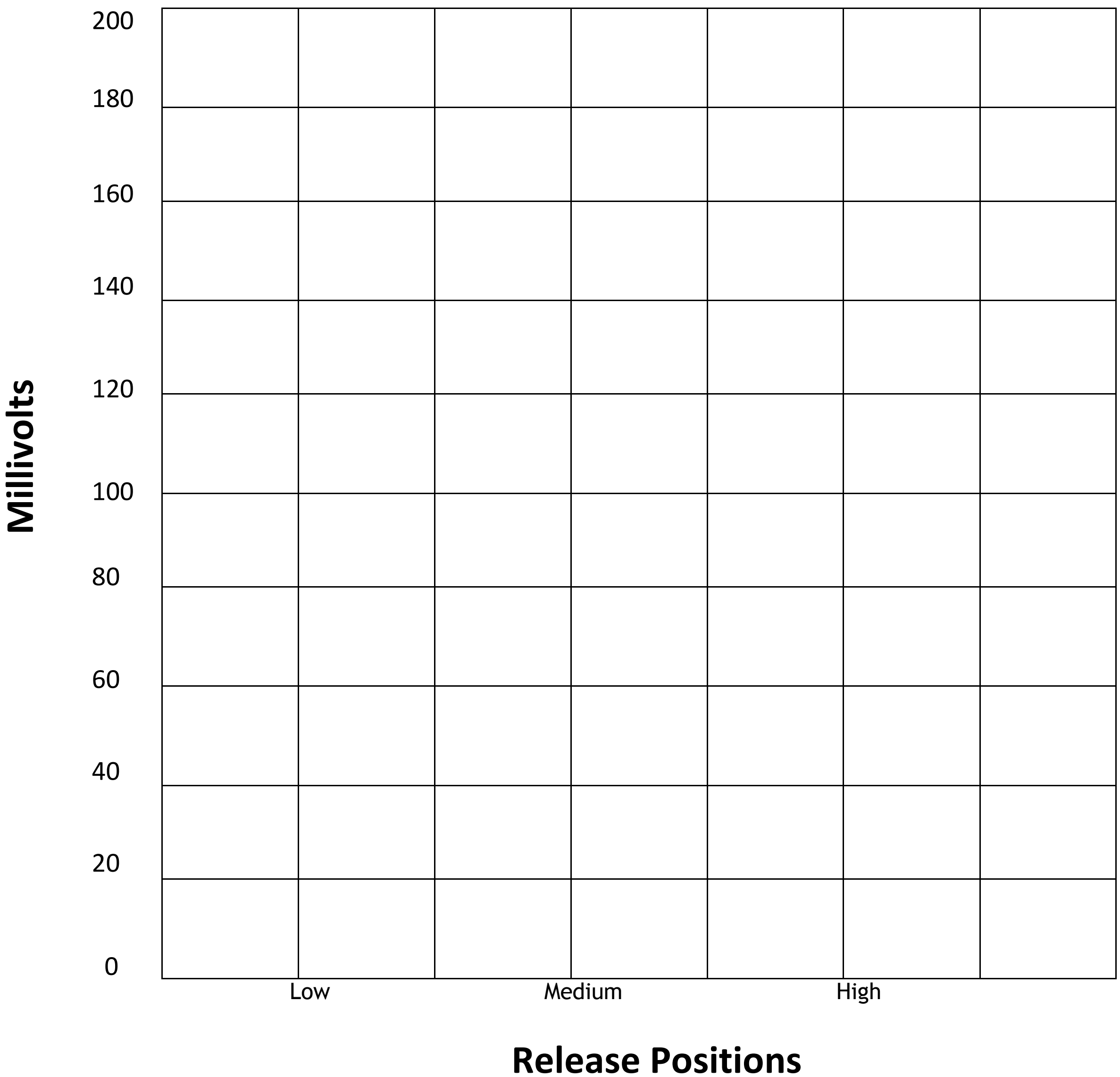
Sum the voltage generated from your three trials and divide by three. Round this number to the nearest whole number.

	Voltage generated from Low position	**Voltage generated from Medium position**	**Voltage generated from High position**
Trial One			
Trial Two			
Trial Three			
Sum of each height (total number when you add up all 3 trials)			
	Divide by 3	Divide by 3	Divide by 3
Average Voltage	mV	mV	mV

Analyze your Data-

Using your results you recorded in the data table complete the bar graph below.

Electricity Generated



Conclusion-

With your group members, discuss and answer the following questions.

1. In your own words, describe what happens when we send a magnet down a ramp and through a coil of wire.

____

____

____

____

____.

2. Based on your experimental data, which "release position" produced the most electricity? Why do you think this happened?

____

____

____

____.

3. What is the relationship between the speed of the magnet and the amount of electricity that is produced?

____

____

____

____.

4. Explain the following statement- a magnetic field creates electricity and electricity creates a magnetic field.

____

____

____

____.

Post-Assessment: Electrical Engineers   Name: _____________

1. What is a complete path through which electricity flows called?

   ____

   ____

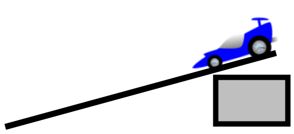
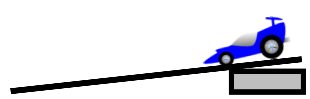
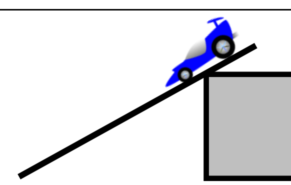
2. What does a continuous flow of negative charges (electrons) create?

   ____

   ____

3. How is electricity created by moving a magnetic field through a coil of copper wire?
   a) Electricity cannot be created this way.
   b) The magnetic field pushes the electrons in the wire into motion, creating electricity.
   c) A battery must be hooked to the magnet to create electricity.
   d) Electrons jump from the magnetic field into the copper wire.

4. Look at the three ramps. If you put the “magnet car” on each of the three ramps, which would you predict would create the biggest electrical current, and why? Assume that the coil of wire is at the bottom of the ramp though it is not included in the sketches.

		
ramp 1	ramp 2	ramp 3

____

____

____

5. How are the principles we discovered in this investigation used in the real world? Give one example. ____

____

____

____

6. Sandra has conducted an investigation to answer the question, “Will the amount of turns (loops) of copper wire in the coil affect the amount of voltage that a magnetic field can create?” The results of her investigation are listed in the table below. Create a bar graph with Sandra’s data. Round each voltage to the nearest whole number. (Example: 1.7 volts would round to 2 volts.)

Turn Investigation	
100 turns	1.3 volts
125 turns	1.8 volts
150 turns	2.1 volts
175 turns	2.6 volts
200 turns	3.8 volts

Turn Investigation

7. Fill in the blanks.
An electric current creates a _________________________, and a

__________________________ creates an electric current.

8. How do you feel about investigating magnets and electricity after completing the investigation? Choose one

- ☐ Electricity has fried my brain!! I more confused than ever!
- ☐ I have learned a lot about electricity and magnets, but I still have some questions.
- ☐ I’m ready to start my career in electrical engineering!

Lesson Sequence

Getting Ready:

1. Before Day One of the lesson, start collecting investigation materials.
2. Administer and score the *Pre-Assessment* and review the results to determine whether any of the *Mini-Lessons* are necessary.
3. Teach any necessary *Mini-Lessons*.

Day One:

1. Introduce investigation. Brainstorm with class and discuss the investigation question, *How does the speed of a magnet moving through a copper wire coil affect the amount of electricity produced?*
2. Show *BrainPop* clip, "Electromagnetic Induction" (http://www.brainpop.com/technology/energytechnology/electromagneticinduction).
3. Teacher demonstration (*optional*).
4. Distribute *Student Investigation Sheets* and discuss expectations.

Day Two:

1. Set up the experimental apparatus.
2. Assign or have students choose roles, using the handout *Investigation Roles*.
3. Conduct investigation and collect data.

Day Three:

1. Students will review and analyze data by creating a bar graph.
2. Students will draw conclusions based on data.
3. (*optional internet extension*) Simulations:
   a. Faraday's Law http://phet.colorado.edu/en/simulation/faradays-law
   b. Faraday's Electromagnet Lab http://phet.colorado.edu/en/simulation/faraday

Day Four:

1. Share findings via group presentations. Teacher will ask "Interview Questions" (*Presentation Interview Sample Questions*) and use the *Presentation Rubric* as a scoring guide.
2. Culminating class discussion.
3. (*optional*) Connect to real-world examples using demonstrations:
   a. PhET simulation, "Generator" at http://phet.colorado.edu/en/simulation/generator
   b. BrainPop "Energy" videos at http://www.brainpop.com/science/energy/
4. Administer, collect, and review the Post-Assessments

Preparation

Important Notes about Preparation

The preparation of the materials can be one way in which the teacher controls the level of inquiry in the investigation. Consider these options:

1. *Set up materials for students in advance. This structures the investigation and may be recommended to support students who would have difficulty with the engineering aspects of the investigation.*
2. *Guide students on how to assemble the investigative instruments. A guided inquiry approach makes the lesson more student-centered.*
3. *Have students engineer the experiment. By moving toward an open-inquiry approach, students have opportunities for problem solving, creativity, and decision-making. This is recommended for students who require more enrichment and/or less structure.*

What You Need

For the class (or teacher):

- ☐ Photos of investigation materials and set-up
- ☐ A computer with Internet access
- ☐ 2 Liter bottle or 4” diameter PVC pipe
- ☐ 1 copper coil loop with 280 turns
- ☐ Sandpaper
- ☐ *Inquiry Investigation Rubric*
- ☐ *Presentation Rubric*
- ☐ *Fluke Multimeter 115® Operation Guide*

For each group:

- ☐ 1 toy car (Matchbox® size)
- ☐ 3 plastic 12 inch long “Hot Wheels” Trick Track®-style connecting track
- ☐ 3 ceramic magnets: 1 7/8” x 3/8” x 7/8” each
- ☐ 1 “loop” of copper coil (approx. 160 feet of 22 gauge copper wire creating a continuous loop with 140 turns)
- ☐ 2 shoe boxes or something else to elevate to the height of 10 cm
- ☐ 1 meter stick
- ☐ 1 roll of masking tape
- ☐ 1 Multimeter (we used the *Fluke*® 115 model)
- ☐ 2 electrical alligator clips or simple circuit switches
- ☐ Sandpaper (if students are creating the circuit)
- ☐ Calculator
- ☐ *Fluke Multimeter 115® Operation Guide,* or similar for your instrument

For each student:

- ☐ *Pre-assessment and Post-Assessment*
- ☐ *Electrical Engineers Student Investigation Sheet*

An instructional kit of the implementation materials for this lesson, provided by a grant from the Toshiba Foundation, is available for loan from Sweet Briar College. For information, please contact:
Arlene Vinion-Dubiel
dubiel@sbc.edu
434-381-6118

Investigation Roles

Leader

Makes sure group members are on task and getting along; keeps track of the time allotted for investigation; makes sure the materials are used properly. If an “Assistant” is not included in the group, then the “Leader” will also be responsible for re-reading the procedure and contacting the teacher with any group needs or concerns.

What a good leader might sound like…

“We should talk about the investigation topic instead of other things”
“We need to keep an eye on the time, we want to be sure we finish our testing.”

Driver

Releases car from indicated distances on track; must be sure to release (not push) with the front of car at each measured line.

Meter Reader

Reads Fluke Multimeter results to “Recorder”; resets meter after each trial.

Recorder

Records data (voltage as indicated by Fluke Multimeter); Makes sure to share all results with the rest of the group if they are not recording them during the actual investigation.

Assistant

Rereads directions to group; makes sure procedure is being followed properly. The assistant will also contact the teacher with any group needs, questions, or materials.

Fluke Multimeter 115® Operation Guide

Operation Instructions

1. **Connect the red Fluke® Multimeter probe to the far right red hole labeled V.**

2. **Place the black Fluke Multimeter probe in the center black hole labeled com.**

3. **Turn the dial to mV symbol.**

4. **Press min/max button (second button from left, located just below digital screen). Make sure the digital screen reads "max" to ensure correct mode of min/max was selected.**

5. **To reset between tests/trials simply turn dial to V symbol and then back to mV symbol.**

6. **For remaining questions and a video usage clip visit the following website-http://www.testequipmentdepot.com/fluke/dmm/115.htm**

7. **For a troubleshooting guide visit the following website- http://assets.fluke.com/manuals/115C117Cumeng0100.pdf**

Inquiry Investigation Rubric

	Student Name	**On Task**	**Model Accurately Constructed**	**Data Collected**	**Demonstrates Understanding of Key Concept**	**Comments** Student Discoveries, Challenges, Observations
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						

Presentation Rubric

Students in Group	

3	2	1
Excellent	Good	Needs Improvement

Score	A. Analyzes Data
	All results are clearly and neatly presented in the table.
	Units of measurement are listed. (mV for millivolt)
	All math is correct.
	Results are represented correctly in a graph.
	Graph is neatly completed and easy to read.
	A SUMMARY of the results are presented to peers in the oral presentation. (Results are not read from table, but summarized in presentation.)

Score	B. Draws Conclusions
	Conclusion questions are clearly answered with complete sentences on conclusion sheet.
	Data is used to answer conclusion questions. Results are connected with conclusions.
	Conclusions are communicated clearly to peers in oral presentation.

Check When Complete	C. Answers Investigation Question
	Investigation question is clearly answered.
	Group explains HOW their results answer the investigation question.
	Group is able to answer questions by their peers correctly using their data.
	Group Total Score

Teacher Comments:

Presentation Interview Sample Questions

(Teacher may ask questions during presentation or hand out the questions for students to answer and share orally when prompted; teachers choice)

1. How does the magnet's magnetic field affect the copper wire?

2. What role does speed play in the creation of electrical energy?

3. How does the creation of this model help you to understand the way electricity is created?

4. Explain the following statement: *A magnetic field makes electricity and electricity makes a magnetic field*.

5. How does electrical induction provide us with energy today?

6. What questions do you still have about electrical induction?

7. Why was the copper wire coil an important item in the investigation?

8. How would the removal of a magnet affect the results? What effect would this have on the amount of electricity produced?

9. How would decreasing the number of turns in the copper coil affect the amount of electricity produced?

10. If you could change one or two things in this investigation, what would they be and why?