IRISE

Illinois Researchers In Partnership With Science Educators

WWW.IRISE.ILLINOIS.EDU

Design of an Electromagnetic Door Lock

Developed by Matthew P. Magill

Description:
Students design a controllable door lock using an electromagnet. The lesson highlights the differences between permanent magnets and electromagnets, and focuses on their associated attractive/repulsive forces. Experiments are carried out to understand the effect of electromagnet design changes. Students finish the lesson by analyzing existing door locks to encourage a feasible design of their own.

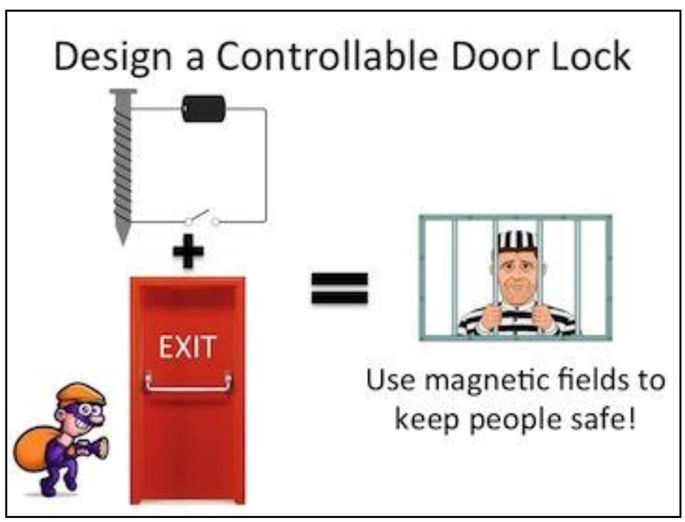
Prerequisites:
Electricity and magnetism basics. This includes a general understanding of voltage, current, electrical conductors, batteries, and permanent magnets.

Instruction Time:
90-150 minutes

Audience:
Middle school science class

Lesson Objective:
Demystify a controllable door lock, understand how it works, and become familiar with how application requirements can affect the end product.

Page **Contents**



Lesson Overview:

This lesson focuses on the application and design of an electromagnet for use in a controllable door lock, and is applicable for grades 6-8. The middle-school students will first refresh their understanding of permanent magnets, electromagnets, their associated magnetic fields, and the resulting attractive/repulsive forces. Next, they will perform experiments to ascertain how changing each of the design variables affects the formation of forces in an electromagnet. This understanding will allow the students to then formulate a design for an electromagnet-controlled door lock. Existing commercial products are then shown to the students in order to stimulate a redesign process.

Background Information:

Conventional mechanical door locks require direct human interaction, and are most often controlled locally with a key. In some situations, this may be extremely undesirable (due to environmental conditions, safety regulations, performance requirements, etc.). One commonly used method to create a access-control door involves the use of an electromagnet. This design uses electrical current and ferromagnetic materials to enable control of the door lock. This electrical system may be activated externally using a keycard, pushbutton, lever, computer, etc., and must also be designed to operate properly during an electrical power outage.

Learning Objectives & Assessment:
Students will be able to (SWBAT):

	Objective	Assessment
Day 1	Experimentally distinguish the ability of different materials to become magnetized by picking up paperclips with an iron rod in the proximity of a magnet	Electromagnet Kit and group discussions
	Identify that electricity can be used to create a controllable magnet	Worksheet 1
Day 2	Explain the importance of controlled experiments when determining the effects of design variables on electromagnet performance	Group discussion
	Classify each primary design variable (battery, # turns, coil layout) as either having a positive or negative relationship with respect to the force of an electromagnet	Worksheet 2 and group discussion
Day 3	Apply the operation of an electromagnet to control a door lock	Worksheet 3
	Demonstrate how constraints can affect the design of a consumer product, and provide specific examples pertaining to the design of a magnetic door lock	Worksheet 3 and group discussion

Alignment to NRC Framework:

This lesson has been designed to align with the National Research Council (NRC) K-12 Science Education Framework for students enrolled in middle school through grade 8.

Disciplinary core ideas

ETS 1: Engineering Design
ETS 1.B: Developing possible solutions

This is satisfied on day 3, as students work together to design a controllable door lock using their recently obtained knowledge of electromagnets. Depending on classroom resources, this is either accomplished using design sketches and mock-ups, or through a combination of hands-on building and hand-drawn models.

Crosscutting concepts

2. Cause and effect: Mechanism and explanation

"Cause and effect relationships may be used to predict phenomena in natural or design systems."

Students first understand the basic operation of an electromagnet and how different designs can affect performance on day 2. They then apply this understanding to design a door lock for their own application on day 3.

Science and engineering practices

3. Planning and carrying out investigations

"Collect data about the performance of a proposed object, tool, process or system under a range of operating conditions."

This is satisfied on day 2 when the students evaluate electromagnet parameter adjustments.

Vocabulary:

Required:

- Permanent magnet
- Magnetic fields
- Voltage
- Current
- Force
- Electrical conductor
- Electromagnet
- Design variable

Supplemental:

- Magnetic dipole
  - "North" and "south" poles
- Trade off
- Fail-safe
- Fail-secure

Materials:

Paper Resources

Day 1 Worksheet

- 1/group

Day 2 Worksheet

- 1/group

Day 3 Worksheet

- 1/group

Physical Resources

Ferrofluid Kit (1/group)

- 1 sealed ferrofluid tube
- 1-3 small magnets
  - Must be strong enough to create spikes in ferrofluid.
- Kits available through Educational Innovations Inc.

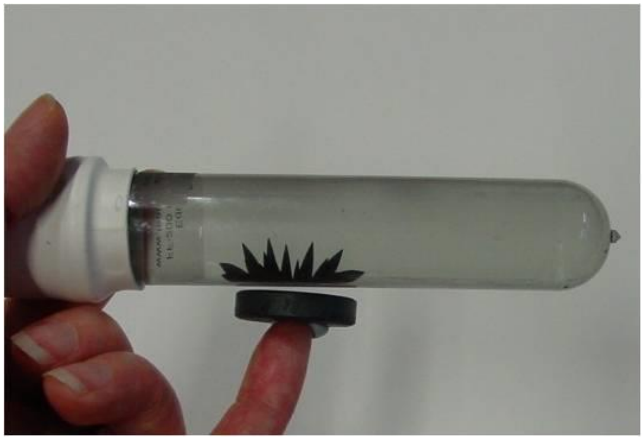


Figure 1: Sealed Ferrofluid tube and magnet.

<u>Conducting pipe demonstration</u> (1/class)

- 1 conducting pipe (preferably copper). Should be at least 2' in length.
  - 1/2" diameter, 0.04" thickness is recommended
    - May be purchased at any hardware store
- 1 strong, disc magnet small enough to fit within pipe.
  - 5/16" x 1/8" (diameter x height) NdFeB magnet is recommended (link)
  - 1 marble, small enough to fit inside the pipe
- Demonstrative YouTube video

Figure 2: Conducting pipe demonstration

<u>Permanent Magnet Kit</u> (1/group)

- 10 small, steel paperclips (uniform size)
- 1-3 small, disc magnets
  - 0.095" x 0.1" (diameter x height) NdFeB magnet is recommended (link)
- 1 - Small iron rod (~ 4-5")
  - A nail, screw, or bolt would suffice.

        - Available at hardware store
    - To ensure material is iron, test that it is attracted to a magnet
- 1 - Small aluminum rod (~ 4-5")
    - A nail, screw, or bolt would suffice
        - Available at hardware store
- 1 - Small wooden rod (~ 4-5")
    - An unsharpened wooden pencil would suffice.

Figure 3: Permanent magnet kit

<u>Electromagnet Kit</u> (1/group)

- 10 small, steel paperclips (uniform size)
- 1 small iron rod (~ 4-5")
    - A nail, screw, or bolt would suffice
        - Available at hardware store
    - To ensure material is iron, test that it is attracted to a magnet
- 1 electromagnet prototype board
    - 1 double AA-battery connector w/ wires
        - Available at electronics or hardware store
    - 1 switch
        - Available at electronics or hardware store
    - 1 base plate (~ 6" X 6")
        - Can be made out of any spare piece of cardboard or plastic
- 2 AA (1.5 V) batteries
- 1 9 V battery
- 1 m (~ 3 ft) of 20 or 22 gauge (AWG) Magnet-Wire
    - Available at electronics or hardware store
- 2 small alligator clips
    - Available at electronics or hardware store

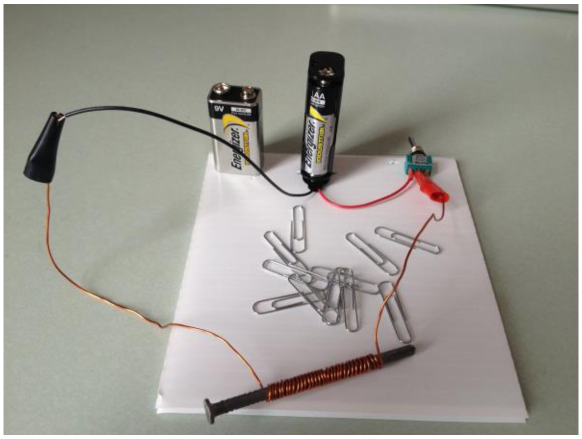


Figure 4: Electromagnet kit.

Technology & Multimedia Resources

Optional

- Computer-connected projector
- Small whiteboards & dry-erase markers

Lesson plan:

This lesson was originally designed to be administered over three 40-minute classes, thus the recommended stopping points for this class structure is provided throughout the following lesson plan.

Engage & Explain

Conduct two demonstrations to hook the students and increase their interest in electromagnetics. This is an "*I do*" component of the lesson.

Magnetic fields are a foreign and "mysterious" aspect of science because they cannot be seen and are difficult to imagine. The ferrofluid demonstration allows students to visualize these fields.

1. *Ferrofluid demonstration*
    - Pass out the *Ferrofluid Kit* and allow students to play with them for 2-3 minutes. A deep understanding of ferrofluids is not important. The demonstration is used to pique their interest.
        - Ask if any students have seen a magnetic liquid (e.g. ferrofluid) before. Describe a ferrofluid as something similar to a liquid etch-a-sketch, or a liquid magnet.
        - Ferrofluids contain very small ferromagnetic particles suspended within a highly viscous liquid. When the fluid is exposed to an external magnetic field (when a permanent magnet is brought near), each individual particle becomes polarized, and becomes its own "bar-magnet." This results in a simultaneous attraction/repulsion of the particles within the fluid.
        - A further explanation can be found on Wikipedia, while a detailed video may also be useful to understand ferrofluids.
        - Ferrofluids are commonly used in loudspeakers, where they act to dampen out unwanted sounds while being a good conductor of heat. This allows speakers to operate more effectively and efficiently, even at high temperatures

If a permanent magnet is moved near a conductor, the act of motion induces a voltage within the conductor (this is called Faraday's Law). This induced voltage gives rise to an electrical current. Electrical currents and magnetic fields are intimately connected. The induced current that flows in the conductor gives rise to a magnetic field. The direction of the current (and hence magnetic fields) is such that it sets up a magnetic field in the direction that opposes the changing magnetic field caused by the falling permanent magnet (Ampere's Law).

To demonstrate this, a disc magnet is dropped down a conducting pipe. As the magnet falls inside the pipe, it will induce currents that flow circumferentially around the periphery (circumference) of the pipe. As stated earlier, these currents create magnetic fields in the opposite direction of the fields created by the falling disc magnet. By having two fields that oppose each other (in opposite directions) magnetic forces arise that oppose the gravitational force exerted upon the magnet. The result is that the magnet will *slowly* fall through the tube, while other non-magnetic components will fall at their normal rate. A nice explanation of this phenomena (due to Lenz's Law) is provided here.

2. *Conducting pipe demonstration*
   - Have a student come to the front of the room to inspect the pipe and ensure it is hollow. Have them touch the magnet and marble to feel the mass and volume. The student could/should share their observations with the rest of the class.
   - Have the student drop a marble down the tube. Observe how fast it falls,
   - Now have the student drop the magnet down the pipe
     - Notes:
       - If the diameter of the magnet is just slightly less than the opening in the pipe, the magnet should fall much slower than the marble.
   - If extra time is available, invite 1 or 2 additional students to drop the magnet down the pipe to see that it is not touching the side as it falls.

(Pass out 1 whiteboard & marker to each group)
Ask the students to use what they already know about electricity and magnetism to explain why the magnet falls so much slower than the marble. Have them break into groups of 2 or 3 to discuss and share ideas. Provide ~ 2-3 minutes before asking a few groups to share their ideas.

- Encourage the students to focus on the magnetic properties of the magnet and electrical properties of the pipe instead of the shape & mass of the objects,
- If appropriate, explain to the class why the magnet falls so slowly:
  - It has to do with the intimate connection between electric currents and magnetic fields. A conductor (i.e. copper) never likes to have the magnetic field around it change, and will produce its own magnetic fields in order to have the total field around stay constant. Since the magnet is always producing a magnetic field, as it falls the magnetic fields in the copper pipe are changing. This causes currents to flow in the copper pipe. These non-zero currents create magnetic fields that oppose those of the magnet. These opposing fields create and upward force and slow down the magnet as gravity pulls it towards the earth's surface.

Ask the students a few questions regarding magnets and their applications. This creates a connection between past and present learning experiences, and allows the students to anticipate the activities that will be covered in the lesson. Students can raise their hands and call out answers.

- Is everyone familiar with magnets (or permanent magnets)?
- Where do you commonly find them?
  - On the refrigerator?
  - Hard disk drive (HDD) in a computer?
  - MRI machine?
  - To hold a nametag on a shirt?

- Large logo on the side of a vehicle?

Explain and Explore

Design Project Introduction:

Inform the students that the reason why they are working with magnets is because they will use magnetic fields to control a door lock in two different applications: a hospital and a zoo. But before they can design a magnetic door lock, they need to better understand magnetics: both its advantages and disadvantages.

Ask the students to brainstorm applications where a door lock should be controlled:

- Front door of school,
- Hotel room,
- Garage door,
- Emergency exit,

(Access-control doors are used essentially wherever/whenever door access is required, and a key is not being used!)

To gauge initial knowledge and background, ask the students to work in groups to discuss and explain how a keycard-access door lock works. Allow students to work for 4-5 min, and have the groups partner-up and share their ideas with another group.

- The keycard reader can be thought of as an electrical switch. If the correct keycard is swiped, then the switch closes and allows electrical current to flow and engage the lock. If an incorrect keycard is used, the switch remains opens and no current is allowed to flow—therefore the door remains locked.

(Collect whiteboards & markers)
Total elapsed time: 25 minutes

Explore

(Hand out Worksheet 1 & Permanent Magnet Kit)
It may be beneficial to use a timer in order to limit this exercise to 5 minutes. The instructor could tell the students that: "…you have *exactly* 5 minutes to fill out the first section of the worksheet. OK, GO!" The exercise becomes more of a challenge/competition when framed in this way.

Break the students into groups, and provide each group with the materials in the *Permanent Magnet Kit*. Tell the students that their goal is to work together as a group to see how many paperclips they can get to stick to the metal and wooden rods *without* touching the paperclips with their fingers (that includes bending them). Allow them to work for ~5 minutes.

- The students will discover that the wooden dowel and aluminum rod are unable to pick up the paper clips. This is because wood and aluminum are both nonmagnetic, and is hardly affected when placed in the presence of external magnetic fields (near the permanent magnet).

- There is a chance that a student is able to get a paperclip to stick to these materials if the magnet is strong and/or the dowel is thin. If this happens, show the group that the attractive forces are extremely small by demonstrating that the iron rod can pick up far more paperclips.

- The students can pick up paperclips with the iron rod by attaching the magnet to one end and picking the paperclips up with the other. This is shown in **Figure 5**
  - This is because iron is ferromagnetic, and can become magnetized by external magnetic fields. Therefore the magnetic fields created by the permanent magnet travel through the length of the rod and out the end near the paper clips. When a magnetic field is near paperclips, an attractive force will exist.

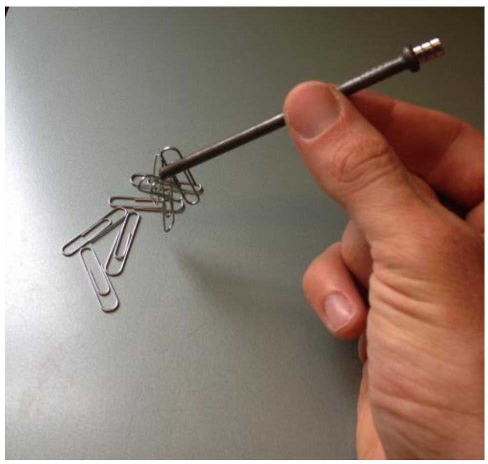


Figure 5: Example of how to pick up paperclips with an iron rod and magnet.

Each group should answer question #1 on Worksheet 1:

1. *"Use a magnet to attract paperclips to another object. How many paperclips can you pick up with each object? How did you accomplish it? (Draw a picture to help explain)"*

Ask 2-3 students to share what was discovered, what worked/what did not?

- What does this tell them about iron and wood? Which material is affected by magnetic fields?

Total elapsed time: 30 minutes

OPTIONAL

This section is optional, and should only be covered if the students are familiar with the concept of magnetic dipoles (magnetic "north" and "south" poles), and the magnetic fields that flow between them.

(Pass out individual whiteboards & markers)

To analyze iron's ability to control and concentrate magnetic fields, draw on the whiteboard or chalkboard, with assistance from the students, the magnetic field created by a bar magnet (as shown in **Figure 6**a).

Now ask each group to draw the magnetic field (on their individual whiteboards) when:

- When the magnet is on the end of the iron rod (**Figure 6**b),
- When the magnet is on the end of the wooden or aluminum rod (**Figure 6**c).

Have each group share their drawings with a teaching assistant for assessment, and explain why they drew it that way.

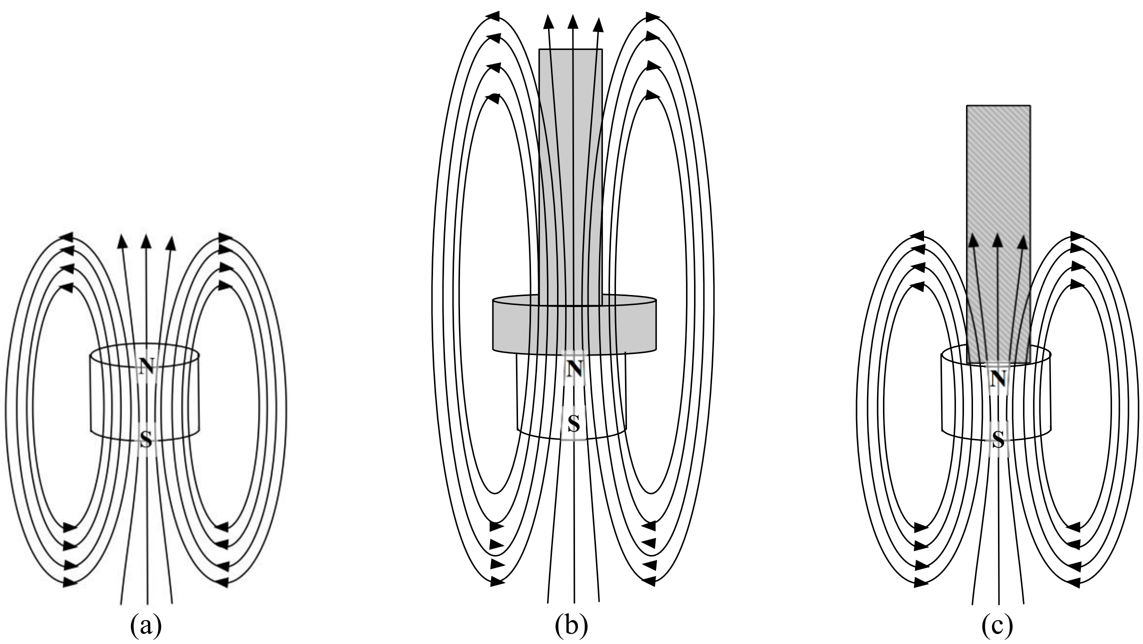


Figure 6: Magnetic fields for (a) a permanent magnet, (b) a permanent magnet in close proximity with an iron rod, and (c) a permanent magnet in close proximity with either a wooden or aluminum rod.

Engage

Each student should answer question #2 on Worksheet 1:

2. *"Can you remove the paperclips from the material without touching it? If not, why?"*

As a discussion with the entire class, guide the students towards questions/answers that deal with the lack of control a magnet provides:

- Does a magnet need to be powered with electricity in order to work? Does it need to be plugged in? Do you need a battery?
  - No - Energy is stored in the magnetic fields created by the magnet, thus no external energy sources (e.g. battery or power cable) is needed to create forces.
- How can you "turn off" a magnet? Is there an "easy" way to turn off its magnetic fields? Can you press a button or turn a switch to have all of the magnets fall off of your fridge?
  - No – Magnets are essentially always "**ON**." Their internal composition always sets up a magnetic field.

"This lack of control is exactly what engineers do not like, so over the course of this lesson, we will learn how make a controllable magnet using electricity, or an **electromagnet"**

Using the *Electromagnet Kit*, demonstrate an electromagnet to the class. Pick up the paperclips and then turn off the electromagnet to show how the paperclips fall off of the iron rod. This illustrates that, unlike the permanent magnet, the user has control over the creation of magnetic fields with an electromagnet!

Each student should answer question #3 on the Day1 worksheet:

3. "Can an electromagnet be turned ON and OFF*?"*

Total elapsed time: 40 minutes

This is a convenient place to stop for a 3-day class

Explain Activities
If a 3-day lesson is planned, it is a good idea to provide an outline for the remaining topics:

- Lesson 2
    - Investigate the primary components of an electromagnet, how it can be used to create a controllable magnetic field, and how changes in its design affect the production of magnetic forces,
    - Quantify magnetic force by counting the number of paperclips that can be collected,
    - Use test results to determine which group can create the most powerful electromagnet.
- Lesson 3
    - Use what we have learned about electromagnets to see how they could be used to control a door lock,
    - Groups will design an application-specific door lock to see how application requirements drive design.

Review & Explore
(Hand out worksheet 2 to each group)
Remind and demonstrate to the students how an iron rod can be used to create forces using magnetic fields by placing a magnet on one end. The problem, however, is that the magnetic cannot be turned "**OFF**." To solve this problem, we can make a magnet using electricity, or an electrical magnet, or and **electromagnet**.

(Hand out Electromagnet Kit)
To avoid rapid depletion of the battery, it is recommended that the batteries be given to students once they have the electromagnet fully built.

Have the students break into the same groups as before, and provide each group with all materials in the *Electromagnet Kit*. Introduce them to the primary components of an electromagnet while pointing out where they are in the kit:

- A source of electricity (battery),
- A wire (where the electricity flows),
- Core (preferably iron),

Guide the students through the process of building an electromagnet:

1) Wrap wire around iron rod 10 times. Leave at least 6 inches of wire on each side,
2) Turn switch to the **OFF** position,
3) Connect the red alligator clip to the center terminal of the switch,
4) Connect the black alligator clip to the exposed end of the black battery wire,

(Hand out AA batteries)

5) Connect the AA battery,
6) To energize the circuit, turn the switch to the **ON** position,
7) Put the end of the nail close to the paperclips to test operation,
8) Turn the switch **OFF** to disable electromagnet,
9) Count number of paperclips that were collected

To ensure that each group member is involved, it is encouraged to assign roles to each student. Below are some examples:

- <u>Switch/Battery Master</u>
  - Duties:
    - Ensure proper battery is connected,
    - Ensure electromagnet is **ON** for a maximum of 10 continuous seconds.
- <u>Coil Master</u>
  - Duties:
    - Control # of coil turns and coil arrangement,
    - Use core to pick up paperclips.
- <u>Paperclip Master</u>
  - Duties:
    - Count # of paperclips collected with electromagnet.
    - Record value in table.

Provide 5 minutes for the students to investigate the operation of the electromagnet operation.

(Collect batteries)
Total elapsed time: 50 minutes

Explore

Suppose we want to change the performance of the electromagnet. Ask the students to suggest aspects of the electromagnet that can be adjusted in order to produce either stronger or weaker forces (pick up fewer or more paperclips). These are called *design variables*.

Students will suggest a wide range of items such as battery size, battery voltage, wire size, number of turns, size of the coil, core materials, core size, temperature etc. Guide the students towards the three variables on Worksheet 2:

- Battery Voltage
  - What would happen if you used a power source with the same voltage, but that would last longer?
    - There would be no instantaneous performance difference, but you would be able to operate the electromagnet for a longer period of time.
  - What would happen if you used a source with a higher voltage?
    - For the same coil, if the voltage is increased, then the current increases as well. Current is the number of electrons that flow each second through the wire. Will more current cause larger forces to be produced?
      - The strength of magnetic fields are proportional to current. The resulting forces (f^e) are proportional to the square of current (i):

$$f^e \propto i^2$$

- # Turns
  - What would happen if we doubled the turns? Tripled the turns?
    - Force is proportional to the square of the number of coil turns (N).

$$f^e \propto N^2$$

- Coil layout
  - What if you put the turns on top of one another?
  - What if the separation between turns was adjusted?
  - What if you wind some one direction, and some more the other direction?
  - What if the turns are not close to the end of the iron rod?
    - The effects of coil layout on electromagnetic forces are a bit more difficult to quantify. The students, however, will find that a design with a tightly wound coil located close to the paperclip pickup location (end of iron rod) will provide the most force.

Total elapsed time: 55 minutes

Elaborate

Before you can design a solution to a problem, you have to understand the fundamental relationships that exist for your system. Comprehension of your system will help shape your overall solution.

Each group will build and test two electromagnet designs to quantify the effect of changing each of the three design variables:

1. Source voltage,

2. # coil turns,
3. Coil layout.

For each design, performance will be measured through a count of how many paperclips could be picked up. Six tests in total will be conducted.

It is crucial that the students are aware of the importance of a controlled experiment, where only one variable is changed at a time. This allows for the isolation of the effects of one variable on system performance. Students should be familiar with this, but it is good to reiterate.

Table 1: Voltage adjustment test results

<table>
<tr><th></th><th>Voltage [V]</th><th># Coil Turns</th><th>Coil Layout</th><th># Paperclips</th></tr>
<tr><td>Design 1</td><td>3 6 9</td><td rowspan="2">10 25 40</td><td rowspan="2"></td><td></td></tr>
<tr><td>Design 2</td><td>3 6 9</td><td></td></tr>
</table>

Worksheet 2 includes a table similar to **Table 1** for each of the three design variables. Each row of the table represents a separate electromagnet configuration, while each column lists the available (and chosen) values of each variable. As displayed in **Table 1**, the students need to circle the desired value of each design variable. Since voltage is the *only* variable with differing values between the "Design 1" and "Design 2," the two designs are able to highlight how source voltage affects electromagnet performance. This process is repeated for the remaining two variables.

Before each group can continue to the next variable, they must obtain an initial from an instructor. The purpose of this is twofold:

1. It allows each group to work at a different pace,
2. It provides the instructor with feedback regarding how well the underlying concepts are being understood.

Before initialing the worksheet, the instructor should ask the students the effect the particular design variable has on performance.

While students are modifying/testing the electromagnets, circulate around the room asking questions:

- What property are you changing?
- Do you think that it will make the electromagnet stronger or weaker? Why?
- When you changed ____ to ____ what happened? Are you surprised?
- Suppose you wanted to make the strongest electromagnet possible. Based on your results, what would you do?
- When you change the electromagnet, how do you know it gets stronger or weaker?
- What are some other ways you could measure the strength of an electromagnet?

OPTIONAL
If there is extra time, or a group finishes early, they may continue on to the "*Electromagnet Design Challenge,*" located at the end of the Worksheet 2.

This exercise allows students to apply what they have learned (in terms electromagnet voltage, # turns, and coil layout) to design the most powerful electromagnet. In order to incorporate design tradeoffs, it is required that the design must satisfy:

- $(\text{Voltage} \times 2) + (\#\text{ turns}) \leq 30$

Total elapsed time: 80 minutes

*****This is a convenient place to stop for a 3-day class*****

Review
(Hand out Worksheet 3)
Review permanent magnets and electromagnets with the students in order to answer the first two questions of Worksheet 3. Allow the students to get into their normal groups and discuss their answers.

Each group should answer questions #1 and #2 on Worksheet 3:

Compare a permanent magnet to an electromagnet

1. *"How are they similar?"*
   - Both produce magnet fields,
   - Both create magnet forces when near conductors (metals).
2. *"How are they different?"*
   - An electromagnet is controllable, a permanent magnet is not,
   - An electromagnet needs an energy source, and permanent magnet does not,
   - Performance of an electromagnet can be easily changed; the same is not true for a permanent magnet.

Recap last lesson, where the students tested different electromagnets to determine the effects of changes in different design variables. Have the students work together in their groups to answer:

"Do each of the following changes increase or decrease the forces created by an electromagnet?"

After all groups have finished, determine the correct answers by using a show of hands or another comparable assessment/engagement method. The relationships should be as follows:

- Increase Voltage → Increases forces
- Increase # coil turns → Increases forces
- Wind coil loosely → Decreases forces

Total elapsed time: 90 minutes

Explore

Introduce the students to the engineering design problem they will be tackling in this lesson. Each group will design a controllable door lock (like the one that operates door locks for hotel rooms, or even the entrance of the school) using a controllable electromagnet. Two illustrative examples are:

- Carle Hospital (Urbana, IL)
    - They want a controllable door lock for entry into an operating room. The operating room requires restricted access, but they do not want the doctors having to use a key for fear that it will become unsanitary or they will lose it. The door must also act as a emergency exit.
- Lincoln Park Zoo (Chicago, IL)
    - The installation is for the access door in the lion's pen. The zookeeper requires that the door be strong, and in case of emergency, they want to be able to remotely control access to the pen.

These two scenarios have been chosen because it is impossible for one lock design to satisfy both problems. The difference has to do with how the door locks operate when the power is out. The first scenario (Carle Hospital) must unlock when the power goes out (also known as fail-safe), while the Lincoln Park Zoo example must have a lock that remains locked when there is no power (fail-secure). Other examples or scenarios may be used, however real-world examples help the students connect with the project, and allow them to feel as though the project is meaningful and real.

Each group should be able to answer questions #3 and #4 on Worksheet 3:

3. *"List at least 3 requirements for your project?"*
   Some possible requirements include:
    - Holding strength
    - Controllable on/off function
    - Operation in the event of a power failure / emergency
        - Fail-safe (unlocked in power outage)?
        - Fail-secure (locked in power outage)?
    - Size

4. *"Should the door be locked when the power goes out?"*
    - Hospital = NO
    - Zoo = YES.

Total elapsed time: 100 minutes

Elaborate
Students will now work together in groups to brainstorm ways in which an electromagnet can be used in their application. Each group should answer questions #5 on the *Day 3 Worksheet*:

5. *"How can an electromagnet be used to control a door lock in your application? Draw a picture of your design."*

The goal of this activity is meant to have the students imagine how to scale up the simple electromagnet they created in order for it to be used to lock/unlock a door. There are many different ways in which this could be done, but the general design should be such that an electromagnet is either housed in the door jam (wall) or door. When electrical energy is supplied to the electromagnet, there will be an attractive force that either locks/unlocks the door through the use of a metal portion of the door (similar to the paper clip).

Total elapsed time: 110 minutes

Evaluate
After all groups have completed their initial designs, an actual controllable door lock will be used to show students how an electromagnet can be used within a commercially available door lock. Using an access-control door (common in most schools), this demonstration can be carried out by having the students study the locking mechanism (both in the door jam and in the door) when the lock is activated and deactivated. Here is a YouTube video that displays the general operation of a fail-secure electric strike door lock. Ask the students to determine if the studied lock is fail-safe or fail-secure.

This analysis will be used to spur a redesign. Instructors will move around the room and verify that all groups have thought about their "fail-secure" and "fail-safe" feature of their design.

Each group should answer question #6 on Worksheet 3:

6. *"After seeing how a REAL electromagnetic door lock works, does your design need any changes? Will it work for your application? Draw your new design."*

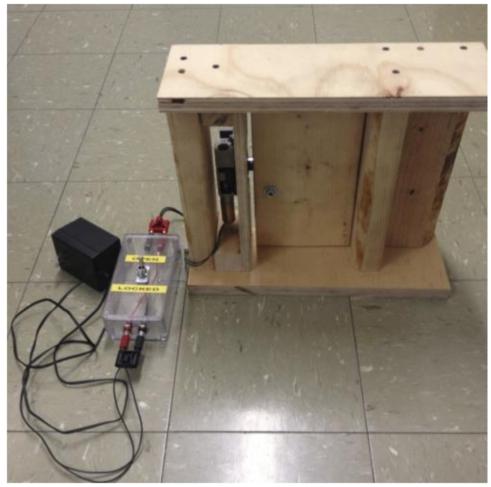
OPTIONAL
If appropriate resources are available, construction of a demonstrative electric strike controlled door is extremely beneficial for the students.

Figure 7 illustrates an example access-control door that was constructed using a Von Duprin 6211 fail-secure electric strike and power supply[1]. The operational door was constructed out of scrap wood, the electric strike was installed on the door jam, and the bolt installed on the door was recovered from a standard door knob set. A large electrical switch was placed in series with the neutral line of the power supply to provide students the ability to manually

[1] Donated by the Locksmith Foreman at the University of Illinois at Urbana-Champaign (www.fs.illinois.edu). Questions regarding door construction can be directed to the author.

activate/deactivate the lock. The electric strike mechanism was left exposed so that students would easily study and investigate the workings of the electromagnet-controlled electric strike door lock.

(a)



(b)

Figure 7: (a) Front view, (b) and rear view of a demonstrative access-control door.

The instructor should now conclude the lesson with a summary of the objectives that were met throughout the lesson

- Day 1
    - Review magnets, and discover how a permanent magnet is not controllable (not desirable in a door lock application),
- Day 2
    - Investigate the primary components of an electromagnet, how it can be used to create a controllable magnetic field, and how changes in its design affect the production of magnetic forces,
- DAY 3
    - Utilize the understanding of electromagnet operation to APPLY it to a problem (this is engineering!),
    - Analyze the performance requirements of the project and your initial design and redesign if necessary.

Total elapsed time: 120 minutes