Electromagnetism and Experimental Design

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Description:
Through scientific inquiry students learn the best way to build an electromagnet and how to set up a proper experimental design.

Objectives:

1. Student will be able to design and carry out an investigation, and finally compare and analyze the results of their investigation about electromagnets
2. Students will understand the underlying concepts of electricity and magnetism
3. Students will be able to recognize how to set up a proper experimental design.

Materials:

1. Several meters length of wire of various gauges, with the minimum gauge being 20.
2. Steel bolt or anything else that could be used as a core.
3. 1.5 volt battery (at least two for every group).
4. paperclips, small nails, or other small metallic (such as iron, nickel or steel) things.

Procedure:

Time Frame: 1 1-hour class period

1. Group students into groups of four.
2. Review Background material on the concept of electricity and magnets.
3. Explain the challenge:
    a. This SEED Engineering Challenge is to build the best electromagnet you can. Your electromagnet will be judged by how much weight it can lift so the “best” electromagnet is the one that lifts the heaviest object or objects.
4. Explain the restraints:
    a. You may use a maximum of 250cm of wire. There is no minimum.
    b. The wire must be no less than 20 gauge. (The higher the gauge, the thinner the wire, so 20 gauge is the fattest wire you may use.
    c. You may use anything for the core, or no core at all.
    d. The electromagnet may be of any shape or size.
    e. Your power source must be a single 1.5 volt battery, no larger than D size.
    f. You may use any ferromagnetic material, such as iron, nickel or steel, as the weight you are lifting. You can try to lift a single object, or may small things such as paper clips or nails. It’s the total weight that counts.
5. Explain the safety precautions:

   a. Use only a single 1.5 volt battery, no larger than D size, as specified. Higher voltages can cause electric shock and a larger battery, even if it is only 1.5 volts, can cause dangerous overheating of some electromagnets.
   b. Even with the precautions in 1, your electromagnet may get hot. If this happens, disconnect it immediately.
6. Review Tips:
   a. **The more turns of wire, the stronger the magnetic field.**
      You are limited to 250cm of wire. You should probably use all of it. The number of turns you can get out of a given length of wire is affected by how you wind it. Neatness counts.
   b. **The larger the diameter of the coil, the stronger the magnetic field.**
      But, since you are limited to a fixed length of wire, increasing the diameter of the coil will mean fewer turns.
   c. **The length of the coil affects the strength of the electromagnet.**
      If the length of the coil is equal to the radius, then increasing it further will reduce the strength of the electromagnet. The relationship between radius and length gets complicated. SEED Expert Ramon Hernandez gives this explanation of how radius and length of an electromagnet coil affect its strength.
   d. **The more current the electromagnet draws, the stronger the magnetic field.**
      Since we have fixed the voltage at 1.5v, the resistance of the coil determines the amount of current it will draw. According to Ohm's Law:
      $I = V / R$
      where I is current, V is voltage and R is resistance. The thinner the wire, the higher its resistance.
   e. **The amount of current that the electromagnet draws may actually be less than what is determined by Ohm's Law.**
      The additional limitation is the power source, which has a maximum current that it can deliver. Not all 1.5v volt batteries are the same in this regard. A size D battery has a greater capacity than an AAA battery. Also, there are many different battery types of the same size. We used an alkaline battery. There are also inexpensive carbon and zinc batteries and a variety of rechargeable types including Nickel-Cadmium. Finally, a fresh battery has a higher capacity than one that has been used for a while.
7. Each group should now begin building and testing various electromagnets in attempt to find the strongest magnet they can build. Have each group write down their procedure they followed to determine which electromagnet they built was the strongest. On a separate sheet of paper they should write down the results of their experiment,
8. When the groups are done designing (30-40 minutes later) the experimental designs should be collected and then each group should receive the experimental design of another group.
9. Give the groups another 20 minutes to complete the procedure of another group, filling out the evaluation handout as they go.

10. After the groups complete their experiments, tally their results on the board to determine which magnet is the strongest.
    a. Ask if they think there are any discrepancies due to different experimental testing procedures.
11. Review Evaluation worksheets aloud, asking each group to present the complications they found with the experimental design they performed.
12. Finally, review the Basics of Experimental Design handout.

Extra:

Have a discussion on how electromagnets are used in everyday life (i.e. MRI)

Basics of Experimental Design

What is Experimental Design All About?

Experimental design is a planned interference in the natural order of events by the researcher. He does something more than carefully observe what is occurring. This emphasis on experiment reflects the higher regard generally given to information so derived. There is good rationale for this. Much of the substantial gain in knowledge in all sciences has come from actively manipulating or interfering with the stream of events. There is more than just observation or measurement of a natural event. A selected condition or a change (treatment) is introduced. Observations or measurements are planned to illuminate the effect of any change in conditions.

The importance of experimental design also stems from the quest for inference about causes or relationships as opposed to simply description. Researchers are rarely satisfied to simply describe the events they observe. They want to make inferences about what produced, contributed to, or caused events. To gain such information ***without ambiguity***, some form of experimental design is ordinarily required. As a consequence, the need for using rather elaborate designs ensues from the possibility of alternative relationships, consequences or causes. The purpose of the design is to ***rule out*** these alternative causes, leaving only the actual factor that is the real cause.

For example, Treatment A may have caused observed Consequences O, but possibly the consequence may have derived from Event E instead of the treatment or from Event E combined with the treatment. It is this pursuit of clear and unambiguous relationships that leads to the need for carefully planned designs.

The kinds of planned manipulation and observation called experimental design often seem to become a bit complicated. This is unfortunate but necessary, if we wish to pursue the potentially available information so the relationships investigated are clear and unambiguous.

The plan that we choose to call a design is an essential part of research strategies. The design itself entails:

- selecting or assigning subjects to experimental units
- selecting or assigning units for specific treatments or conditions of the experiment (experimental manipulation
- specifying the order or arrangement of the treatment or treatments
- specifying the sequence of observations or measurements to be taken

By convention, the problems of design to not ordinarily include details of sampling, selection of measurement instruments, selection of the research problem or any other nuts and bolts of procedure required to actually do the study.

Experimental Design Terminology

The group in an experiment which receives the specified treatment is called the ***Treatment Group*** or the experimental group. However, the term ***Control Group*** refers to another group assigned to the experiment, but not for the purpose of being exposed to the treatment. Thus, the performance of the control group usually serves as a baseline against which to measure the effect of the full treatment on the treatment group.

A ***variable*** refers to almost anything under the sun. There are only two kinds of stuff in the world for researchers: variables and constants. As a result, almost any concept, or thing, or event they are interested in, that varies or can be made to vary, and that is related to their research can be called a variable. Researchers pay particular attention to variables that may influence the results (this is of MUCH concern to researchers).

Extraneous variables (external to the experiment) are variables that may influence or affect the results of the treatment on the subject.

A variable of specific experimental interest is sometimes referred to as a ***factor***. Ordinarily the term factor. Ordinarily, the term is used when an experiment involves more than one variable. These variables are often identified as factors and are labeled "Factor A" and "Factor B," etc. ***Level*** refers to the degree or intensity of a factor. Any factor may be presented in one or more of several levels, including a zero level.

Randomness refers to the property of completely chance events that are not predictable (except in the sense that they are random). If they are truly random, examining past instances of occurrence should give the researcher no clues as to future occurrences. Thus, if we were to predict outcome from perfect pairs of dice rolled in an unbiased way (which are random events), previous rolls give no clue. Randomness becomes important in the design of the experiments primarily in the assignment of subjects to groups. Researchers feel more secure about the results of their studies if subjects have been randomly assigned to groups. ***Random assignment*** of subjects to groups tends to spread out differences between subjects in unsystematic (random) ways so that there is no tendency to give an edge to any group.

Randomization, or random assignment, refers to a technique of assignment or ordering such that no consistent or systematic effect in the assignment is tied in with the method. Elimination of such systematic influence upon assignment or selection allows for chance assignment. Approved ways of generating chance assignments involve tables of random numbers or the use of computer software with random number generators. However, typically, researchers frequently resort to simple counting off, flipping a coin, and other short cuts.

Another way of selecting subjects is simply to use intact groups: such as all the students in a given classroom, or all of the patients in a hospital. Researchers are usually worried whether the students were assigned to the classroom in a non-random way, or whether certain patients self-selected a hospital for a particular reason. The problem is whether some subtle factors were operating to exert a bias of selection factors in the assignment to groups.

Ex post facto refers to causal inferences drawn "after the fact." For in the ex post factor study, the causal event of interest has already happened. These are known as non-experimental studies and are often contrasted with experimental studies. A typical example of this type of research would be to compare two groups of patients in a hospital, one treated with Drug A and the other treated with Drug B and then trying to infer a difference in the performance of the two drugs.

Variance refers to the variability of any event. If one uses a fine enough measuring device, one can find differences between any two objects or events.

The inside logic of an experiment is referred to as ***internal validity***. Primarily, it asks the question: Does it seem reasonable to assume that the treatment has really produced the measured effect? Extraneous variables which might have produced the effect with or without the treatment are often called "threats to validity."

External validity, on the other hand, refers to the proposed interpretation of the results of the study. If asks the question: With what other groups could we reasonably expect to get the same results if we used the same treatment? If Treatment X resulted in lowered blood pressure in middle age men, could you logically claim that it will produce the same effect in older women?

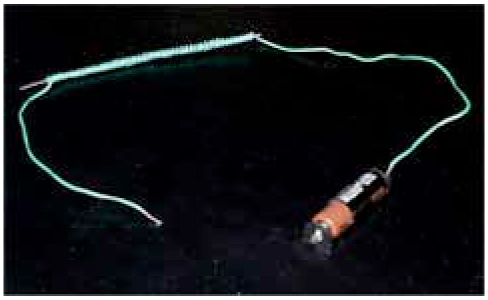
Blocks usually refers to categories of subjects with a treatment group. For example, we might divide the group into older, middle aged, and younger patients and further divide the groups into a group treated with Drug A and another treated with Drug B. The advantage is to enable us to discover how the treatment affects each of the age groups. For example, we might find that overall, Drug B out performs Drug A, except for older patients, where Drug A out performs Drug B. This phenomenon is known as an *interaction* between treatment (the Drug) and subject characteristics (age).

Interaction refers to variables in the treatment which may interact with each other. It may make a difference whether a variable is used by itself, with another, or with different levels or degrees of another. Higher order interactions are possible. One factor may depend on the presence or absence of two other factors; termed a second-order interaction.

The ***Hawthorne Effect*** refers to the behavior of interest being caused by subject being in the center of the experimental stage, e.g., having a great deal of attention focused on them. This usually manifests itself as a spurt or elevation in performance or physical phenomenon measured. Although the Hawthorne Effect is much more frequently seen in behavioral research, it is also present in medical research when human subjects are present. Dealing with this problem is handled by having a control group that is subject to the same conditions as the treatment groups, then administering a placebo to the control group. The study is termed a ***blind*** experiment when the subject does not know whether he or she is receiving the treatment or a placebo. The study is termed ***double blind*** when neither the subject nor the person administering the treatment/placebo knows what is being administered knows either.

Electromagnetism Background

What Is an Electromagnet?



When electricity flows through a wire, a magnetic field is produced. Most electromagnets consist of wire that is coiled around a core made of iron or steel. Here's an example that we used in the Magnetic Relaxation Experiment.

The wire is wound around a straightened paper clip and is attached to one end of the battery. When the loose end of the wire is touched to the other end of the battery, electricity flows through the wire and the paper clip becomes magnetized.

This happens because the iron atoms in the paper clip are arranged in clusters known as domains. These are like little magnets, each with a north and a south pole. They are usually jumbled up and pointing every which way so their magnetic fields cancel each other out. When the domains are all lined up in the same direction the piece of metal is a magnet. When electricity flows through the wire that is coiled around the paper clip, the domains line up.

Another type of magnet is a permanent magnet, such as the ones you might stick on your refrigerator. A permanent magnet is made of iron or another ferromagnetic metal such as nickel or cobalt. The domains are lined up when the magnet is manufactured and stay that way.

Electromagnetism Evaluation

1. What are the variables?

2. What are the constants?

3. Is the procedure clear and easy to follow? If not, be specific.

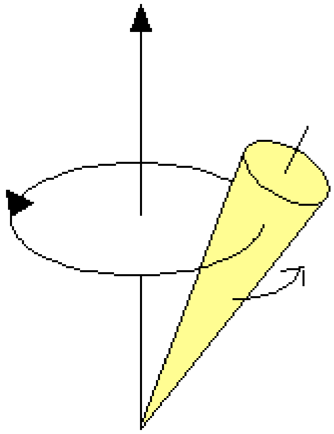
4. Did you get the same results as the group that designed this experiment? If not, predict why.

Magnetic Resonance Imaging (MRI)
How MRI Works

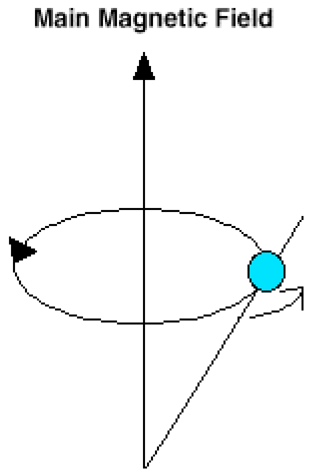
Resistive magnets consist of many windings or coils of wire wrapped around a cylinder or bore through which an electric current is passed. This causes a magnetic field to be generated. If the electricity is turned off, the magnetic field dies out. These magnets are lower in cost to construct than a superconducting magnet (see below), but require huge amounts of electricity (up to 50 kilowatts) to operate because of the natural resistance in the wire. To operate this type of magnet above about the 0.3-tesla level would be prohibitively expensive.

Superconducting magnets are by far the most commonly used. A superconducting magnet is somewhat similar to a resistive magnet -- coils or windings of wire through which a current of electricity is passed create the magnetic field. The important difference is that the wire is continually bathed in liquid helium at 452.4 degrees below zero. Yes, when you are inside the MRI machine, you are surrounded by a substance that is that cold! But don't worry, it is very well insulated by a vacuum in a manner identical to that used in a vacuum flask. This almost unimaginable cold causes the resistance in the wire to drop to zero, reducing the electrical requirement for the system dramatically and making it much more economical to operate. Superconductive systems are still very expensive, but they can easily generate 0.5-tesla to 2.0-tesla fields, allowing for much higher-quality imaging.

The human body is made up of untold billions of atoms, the fundamental building blocks of all matter. The nucleus of an atom spins, or **precesses**, on an axis. You can think of the nucleus of an atom as a top spinning somewhere off its vertical axis.



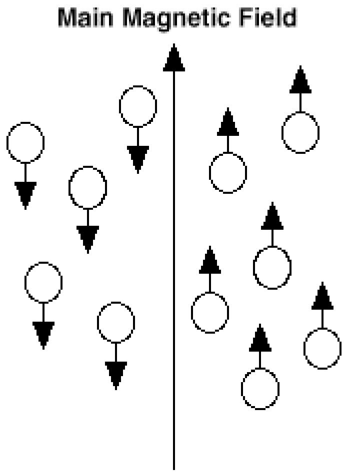
A top that is spinning slightly off the vertical axis is precessing about the vertical axis.



A hydrogen atom precesses about a magnetic field.

Imagine billions of nuclei all randomly spinning or precessing in every direction. There are many different types of atoms in the body, but for the purposes of MRI, we are only concerned with the **hydrogen atom**. It is an ideal atom for MRI because its nucleus has a **single proton** and a large **magnetic moment**. The large magnetic moment means that, when placed in a magnetic field, the hydrogen atom has a strong tendency to line up with the direction of the magnetic field.

Inside the **bore** of the scanner, the magnetic field runs straight down the center of the tube in which we place the patient. This means that if a patient is lying on his or her back in the scanner, the hydrogen protons in his or her body will line up in the direction of either the feet or the head. The vast majority of these protons will **cancel each other out** -- that is, for each one lined up toward the feet, one toward the head will cancel it out. Only a couple of protons out of every million are not canceled out. This doesn't sound like much, but the sheer number of hydrogen atoms in the body gives us what we need to create wonderful images.



All of the hydrogen protons will align with the magnetic

field in one direction or the other. The vast majority cancel each other out, but, as shown here, in any sample there is one or two "extra" protons.

The MRI machine applies an RF (radio frequency) pulse that is specific only to hydrogen. The system directs the pulse toward the area of the body we want to examine. The pulse causes the protons in that area to **absorb the energy** required to make them spin, or **precess**, in a different direction. This is the "**resonance**" part of MRI. The RF pulse forces them (only the one or two extra unmatched protons per million) to spin at a particular frequency, in a particular direction. The specific frequency of resonance is called the **Larmour frequency** and is calculated based on the particular tissue being imaged and the strength of the main magnetic field.

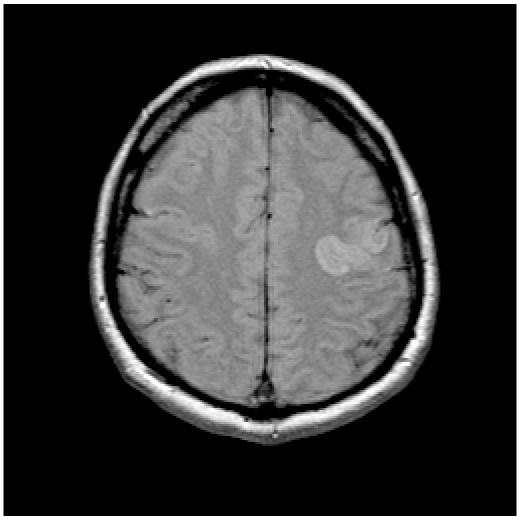
When the RF pulse is turned off, the hydrogen protons begin to slowly (relatively speaking) return to their **natural alignment** within the magnetic field and **release** their excess stored energy. When they do this, they give off a signal that the coil now picks up and sends to the computer system. What the system receives is mathematical data that is converted, through the use of a **Fourier transform**, into a picture that we can put on film. That is the "imaging" part of MRI.

Why would your doctor order an MRI? Because the only way to see inside your body any better is to cut you open. MRI is ideal for:

- Diagnosing **multiple sclerosis** (MS)
- Diagnosing **tumors** of the pituitary gland and brain
- Diagnosing **infections** in the brain, spine or joints
- Visualizing **torn ligaments** in the wrist, knee and ankle
- Visualizing **shoulder injuries**
- Diagnosing **tendonitis**
- Evaluating **masses** in the soft tissues of the body
- Evaluating **bone tumors**, **cysts** and **bulging or herniated discs** in the spine
- Diagnosing **strokes** in their earliest stages

MRI Example

Acute stroke: speech arrest



This acute cerebral infarction can be seen to involve the left pre- central gyrus. Abnormally bright signal is seen here because of the presence of excess water which has a prolonged relaxation time. As tissue has become infarcted and edematous, the sulcus is no longer identifiable. Compare the infarcted side with the normal right side. As you navigate through the datasets, change between the three types of image with the buttons at right, or click on the timeline tickmark for the desired dataset.