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ABSTRACT

This teaching unit is designed to help students in grades 5 to 8 explore the concepts of patterns, functions, and algebra in the context of propelling spacecraft. The units in the series have been developed to enhance and enrich mathematics, science, and technology education and to accommodate different teaching and learning styles. Each unit consists of background notes for the teacher, a list of teacher resources, and two activities, one of which is Web-based, complete with blackline masters. Also included are suggestions for extensions to the problems and their relationships to national mathematics, science, and technology standards. In this activity, students learn how patterns, functions, and algebra can help National Aeronautics and Space Administration (NASA) engineers design new ways of propelling spacecraft and how electricity and magnetism are being used to replace the fuel-consuming rocket propulsion commonly used to deliver a push to spacecraft. (MM)

Program 3 in the 2000-2001 Series

Patterns, Functions, and Algebra:

Wired for Space

QUICK INDEX

Educator's Guide	
Teachers & Students	Grades 5-8

Publication Number EG-2000-10-17-LaRC

PROGRAM OVERVIEW

SUMMARY AND OBJECTIVES

In *Patterns, Functions, and Algebra: Wired for Space*, students will learn how patterns, functions, and algebra can help NASA engineers design new ways of propelling spacecraft and how electricity and magnetism are being used to replace the fuel-consuming rocket propulsion commonly used to deliver a push to spacecraft. Students will discover three projects that use electromagnetism in a dynamic way: the Magnetic Levitation Launch System (MagLev), the Propulsive Small Expendable Deployer System (ProSEDS), and the student-designed Icarus satellite. Students will observe NASA engineers using algebra to design and test the Icarus satellite. Through classroom and on-line activities, students will make connections between electricity and magnetism and between NASA research and the mathematics, science, and technology they learn in their classroom.

INTERACTIVE ACTIVITIES

Questions are posed throughout the video by Norbert, the animated cohost of NASA CONNECT. These questions direct the instruction and encourage students to think about the concepts being presented. An icon appears in the video to suggest to teachers an appropriate place to pause the video and discuss the answers to the questions. Students record their answers on the Student Cue Cards (p. 23).

The hands-on Classroom Activity (p. 2), entitled *Make it Go!*, is classroom-tested and aligned with the National Council of Teachers of Mathematics standards, the National Science Education standards, and the International Technology Education Association standards for technological literacy. Students will construct, operate, and collect data from a device that demonstrates electrodynamic propulsion. They will explore how the amount of current flowing through a wire coil affects its deflection in a magnetic field. This activity provides an opportunity for students to gather and then discuss complicated data in terms of broad, sweeping trends. See Figure 1, an illustration of the **electrodynamic demonstrator unit (EDU)**.

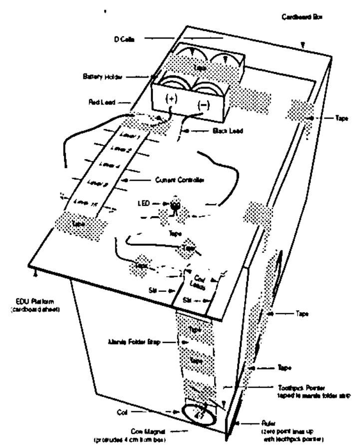


Figure 1. Overview of EDU setup. The coil moves when the circuit is closed. Students investigate how the current level affects this motion. (For enlarged view, see p. 16.)

The on-line activity, entitled the Internet Plasma Physics Education eXperience (IPPEX), is aligned with the National Council of Teachers of Mathematics standards, the National Science Education standards, and the National Educational Technology standards. This activity invites students to explore basic concepts involved with electricity and magnetism, such as static charge, moving charge, voltage, resistance, and current. IPPEX is located in Norbert's lab at **http://connect.larc.nasa.gov/wired/lab.html.**

RESOURCES

Teacher and student resources (pp. 25 and 26) support, enhance, and extend the NASA CONNECT program. Books, periodicals, pamphlets, and web sites provide teachers and students with background information and extensions. In addition to the resources listed in this lesson guide, the NASA CONNECT web site **http://connect.larc.nasa.gov** offers on-line resources for teachers, students, and parents. Teachers who would like to get the most from the NASA CONNECT web site can access Norbert's Lab and receive assistance from the *Lab Manager.*

THE CLASSROOM ACTIVITY

BACKGROUND

Make it Go! is designed to demonstrate the same force that NASA will use in its propellant-free satellite propulsion system, to be tested in the ProSEDS mission. Unlike MagLev, which offers the promise of providing lower cost and safer launches by replacing much of the rocket fuel needed to get spacecraft into orbit, ProSEDS would be employed once the spacecraft reaches orbit.

High-speed MagLev trains use magnetism to lift the train body off the tracks, causing them to ride not on the tracks but through the air. Once the vehicle is off the tracks, electromagnets are arranged so that the magnetism pushes the train forward. Magnetism dramatically reduces frictional forces and the use of energy required to overcome them. More energy can be used to propel the vehicle forward—and fast! Adapted to spacecraft, MagLev could be used in the first phase of a launch to boost the spacecraft upward along an inclined track. Once the spacecraft reaches a critical speed, rockets would take over and provide the final push required to send the vehicle into orbit.

Typically, an orbiting spacecraft expends propellants (fuels) to direct its motion. Propellants help push the vehicle into higher orbit or force it to leave orbit quickly once the craft is out of service. When replacing these fuels, the ProSEDS system employs a long, electrically conducting wire tethered to a spacecraft. The Earth's magnetic field, which extends into the zone in which satellites orbit the Earth, will give a magnetic push to this current-carrying tether. The tether will transfer this force to the spacecraft, making it move. Soon, ProSEDS technology will be tested on a satellite called Icarus. The object of the test will be to examine how well ProSEDS will work to rapidly force the satellite out of orbit (to burn up in Earth's atmosphere). The satellite is named Icarus after the tragic Greek mythological character who fell to Earth while trying to fly too close to the Sun with waxen wings.

Students will work in small teams to construct a device, make observations, and collect data on how different levels of current affect the distance that the coil moves. The objectives of the activity are to (1) provide students with a concrete example of the technology presented in the NASA CONNECT video, (2) provide an opportunity for students to explore the relationship between electric current and the movement of a coil in a magnetic field, and (3) discuss the phenomenon in terms of broad patterns or trends that are both qualitative and quantitative. Through their explorations, students make predictions, test them, take measurements, and discuss and graph patterns.

As a project that will expand your students' math competencies, the activity helps develop their ability to think about patterns and trends in the way two variables relate to one another, with consideration of qualitative observations, quantitative data relating to these observations, and the visualization of these data in the form of a graph—all of which support and develop the basic pattern or trend that relates current levels in the circuit to the distance the coil moves.

While the ability to recognize and "see" an overall trend is an important precursor to more formal understandings of the concepts of linear and nonlinear functions, this unit was not designed to provide a formal, concrete introduction to functions; the nature of the relationship between the magnet and the current in the coil is too complex to provide a simple introduction to functions.

NATIONAL STANDARDS

MATHEMATICS STANDARDS

- Understand patterns, relations, and functions.
- Use mathematical models to represent and understand quantitative relationships.
- Analyze change in various contexts.
- Understand measurable attributes of objects and the units, systems, and processes of measurement.
- Apply appropriate techniques, tools, and formulas to determine measurement.
- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them.
- Develop and evaluate inferences and predictions that are based on data.
- Recognize and apply mathematics in contexts outside mathematics.
- Use representations to model and interpret physical, social, and mathematical phenomena.

SCIENCE STANDARDS

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry
- Motions and forces
- Transfer of energy

TECHNOLOGY STANDARDS

- Various relationships exist between technology and other fields of study.
- Throughout history, innovations in technology have resulted from the demands, values, and interests of individuals, businesses, industry, and societies.
- The process of experimentation, which is common in science, can also be used to solve technological problems.
- Some technological problems are best solved through experimentation.
- Follow step-by-step directions to assemble a product.

INSTRUCTIONAL OBJECTIVES

Students will be able to

- construct an **electrodynamic demonstrator unit (EDU)**.
- use the EDU to observe that changing the current in a circuit affects the light emitted from an LED (light emitting diode).
- observe and understand that a wire with electricity flowing through it can be made to move in the presence of a magnet.
- observe that changing the current in a circuit affects the amount of movement induced in the electric wire when a magnetic field is present.
- measure, record, and graph the relationship between the electric current and the wire movement.
- discuss general trends in the data.

VOCABULARY

Here are some terms that are used throughout this activity with which your students may not be familiar. You may want to spend some time developing their understandings of the relevant concepts.

current - the flow of electrons or charged particles in an electric circuit
force - a push or a pull on an object
electrodynamic - related to the interactions of electric currents with magnetic fields
electromagnetic - related to electricity and magnetism
trend - a general pattern of how a system behaves, relating two or more variables to one another

PREPARING FOR THE ACTIVITY

MATERIALS

For items that may be difficult to find, Radio Shack part numbers and pricing information are included.***NASA does not endorse Radio Shack as a supplier of materials;** these materials can be replaced with parts from other suppliers, as well.

FOR ENTIRE CLASS
wire cutters
scissors

PER STUDENT TEAM (2-3 STUDENTS)

1 tall, sturdy **box** (at least 30 cm high, 15 cm wide, and 30 cm deep), with magnet hole prepared (See instructions for preparing the magnet hole in the Advance Preparation section of this guide, p.6.)

1 piece of **corrugated cardboard** about 15 cm x 30 cm (approximately the size of the box top) to serve as a platform for the batteries, LED, and Current Controller.

Electrical resistors in the following sizes:

Required for Basic activity	Used in Extension activity
22 ohm	33 ohm
82 ohm	47 ohm
220 ohm	68 ohm
470 ohm	100 ohm
1000 (1K) ohm	150 ohm
	330 ohm

All these resistors may be obtained from Radio Shack in packets of 5 for 49¢.

1 roll of **magnet wire** (30 or 32 AWG), with enamel coating
(Radio Shack offers a magnet wire 3-pack: 40 ft of 22 gauge, 75 ft of 26 gauge, and 200 ft of 30 gauge wire. Part number 278-1345; $3.99)

alligator clip leads (small toothed)
(Radio Shack sells 14 in. length, double-headed alligator clip leads. Part number 278-1156; package of 10, $3.99)

24 in. length, **double-headed alligator clip leads**
(Radio Shack: Part number 278-1157; package of 8, $3.99)

2 fresh **D cell batteries**

battery holder for two D-cells (for D-cells with wires/leads attached)
(Radio Shack: Part number 270-386; $1.59)

1 **LED** (light emitting diode)
(Radio Shack provides an LED assortment: Part number 276-1622; package of 20, $2.29)

tape (cellophane or masking)

fine **sandpaper** for removing enamel insulation from magnet wire

1 **Current Controller**, prepared by teacher ahead of time (See instructions on Current Controller Templates, Figure 5, p. 20.)

strip of **manila folder**, 3 cm x 16 cm (prepared ahead of time by teacher)

toothpick

mm ruler

film can (container for 35-mm film; available free to teachers at most film developing establishments)

cow magnet (available through science education supply catalogues)

* The use of trademarks or names of manufacturers in this report is for accurate reporting and does not constitute an official endorsement, either expressed or implied, of such products or manufacturers by the National Aeronautics and Space Administration.

TIME

Overall, this activity will take four 45-minute sessions.

Introduce and demonstrate teacher's EDU and build student EDUs with LED (steps 1 and 2): 90 min (two 45-min sessions).

Add coil and magnet to EDU and observe, measure, graph, and interpret the effects of varying levels of electric current (steps 4 through 5): 90 minutes (two 45-min sessions).

ADVANCE PREPARATION

1. Construct and become familiar with the behavior of the electrodynamic demonstration unit (EDU) (see enlarged view of Figure 1, p. 16). Student Work Sheets 1 and 2 (pp. 13-15) provide instructions for building the EDU.
2. Once you have built the EDU, try all the suggested activities before you conduct the lesson and demonstrate a completed EDU to the entire class. The initial demonstration to the class is done without the magnet and coil in place, so remove them before demonstrating the model.
3. Prepare 3-cm x 16-cm manila folder strips (1 per student team)
4. Prepare one Current Controllers (Figure 1a, p. 6) for each student team, according to the instructions on the Current Controller Template (Figure 5, p. 20).
5. Cut magnet holes in boxes. Each hole should be on the front, vertical face of the EDU, 2-1/2 cm from the right edge and about 20 cm from the top of the box.

NOTE: Making this hole can be a little tricky, so we recommend you try it on another box or another part of the box before cutting the "real" hole. The important thing is that the magnet be held in the hole firmly and perpendicular to the box. One good way is to make a hole slightly smaller than the magnet and then push the magnet into that hole.

CAUTION: The LED can be damaged by excess current running through it. To limit the current and avoid such damage, always use the current regulator in the circuits that you connect.

NOTE: The LED has polarity. It operates only when the current flows through it in a specific direction. Make sure that the negative lead from the battery holder is connected to the shorter lead on the LED. (The leads are the small metal "legs" sticking out from the bottom of the LED.) If the LED does not work, try reversing the leads. That should take care of the problem.

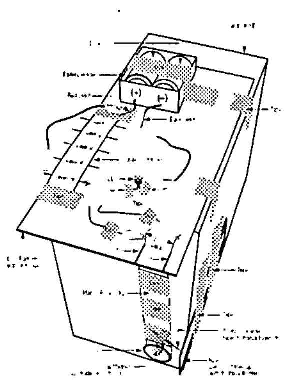


Figure 1. (as seen on p. 1)
Overview of EDU Setup.
(For enlarged view, see Figure 1, p.16.)

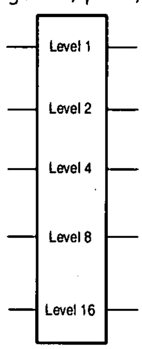


Figure 1a.
Front view of completed Current Controller.
(For instructions, see Figure 5, p. 20.)

Figures in the Activity

THE ACTIVITY

STEP 1: INTRODUCE AND DEMONSTRATE THE MODEL (THE EDU)

A. INTRODUCE THE ACTIVITY

1. Begin this activity with the idea that you will be exploring the same effect that NASA is hoping to use to propel satellites in space—electrodynamic propulsion. Also introduce the idea that the way you will be exploring this effect is to look for patterns and trends in how the effect acts. Point out that scientists and engineers explore such patterns in their work. Math is a useful tool that helps us examine and describe patterns and trends.
2. Arrange students so that everyone can get a good look at your **electrodynamic demonstration unit (EDU)**. Ask them to describe it. Explain that you have set up one continuous circuit that connects batteries, a bulb (LED), and a long, continuous coil to one another. Is the circuit on? How can students tell? As a class, trace the (would-be) path of electricity, identifying where there is no connection.
3. Relate the EDU to NASA's electrodynamic propulsion system (featured in the NASA CONNECT video). Point out that the device you are working with is a good model of NASA's ProSEDS mission. NASA will make electricity run through the long wire tether, represented by the coiled wire. The Earth's magnetic field is represented by the cow magnet (see Figure 1, p. 16). The magnetism acts on the current and makes the wire move, just as the tether and satellite will move in Earth's weaker, but larger magnetic field.

B. DEMONSTRATE THE CIRCUIT (WITHOUT THE COIL)

NOTE: For this part of the activity, keep the Current Controller setting at Level 16—the greatest current. You may wish to dim the room lights so that the LED light is more visible.

This step establishes a common understanding of the circuit. You also have a chance to introduce a familiar phenomenon—the generation of light upon the closure of a circuit—as an indicator that current is flowing. The lit LED will serve as an indicator of flowing current throughout the rest of this activity.

1. Tell students you want to look only at the LED for now, so you are going to take the coil out of the circuit. Close the EDU circuit in a way that bypasses the coil. Ask students to share their observations of what happens. (The LED will light, showing that there is a continuous, electrically conducting path.)
2. As a class, trace the path of electricity through the circuit to verify that the circuit is closed.
3. Show and describe the purpose of the Current Controller to students, taking note of the relationship between the current levels. (The purpose of the Current Controller is to allow students to set the current to very specific levels. A higher current level setting corresponds to a greater amount of current in the circuit. The levels are set so that increasing the setting from one level to the next highest one results in a doubling—approximately— of the amount of current. Thus, Level 4 provides twice as much current as Level 2.)
4. Ask students to think about and predict what will happen to the LED when the circuit is set at the different current levels. Record the predictions on the board, emphasizing that students are making qualitative predictions about how the current level and the illumination of the LED relate. (Groups of students may have a variety of opposing opinions. They may say nothing will change or that the LED will shine more brightly with greater or with lower current levels.)

5. Do not change the current level on your model. Instead, challenge student teams to build their own EDUs and test their predictions.

STEP 2: BUILD EDUs WITHOUT COILS OR MAGNETS

NOTE: This step allows students to experience firsthand the EDU circuit and the Current Controller. They can verify for themselves that changing the levels on the Current Controller actually changes the current flowing in the circuit. The LED serves as an indicator of the amount of current flowing in the circuit. In Step 3, they build the coil and add it, along with the magnet, to the EDU.

A. BUILD EDU CIRCUIT WITHOUT COILS OR MAGNETS

1. Distribute Student Worksheet 1 (p. 13) to each team of 2-3 students and distribute the materials listed.
2. Discuss the construction steps before students begin building their EDUs.
3. Circulate among the groups and help them construct their EDUs.

B. EXPLORE EDU AND LED

1. Encourage students to explore how the brightness of the LED changes as the current level changes.
2. Circulate among the working groups to encourage careful and systematic observations.

C. DISCUSS STUDENT OBSERVATIONS AS A CLASS

1. Compare student observations to their predictions.
2. Challenge students to make one (or more) statements about the relationship they observe between the current level and the illumination of the LED. Is there a general trend to this relationship?
3. Emphasize that the trend we observe holds true as the current levels get higher or lower. The light from the LED gets brighter or dimmer with higher or lower current levels. Some trend statements might be "The higher the current, the brighter the LED lights," or "The lower the current, the less brightly the LED lights."
4. Ask students to predict what they would observe if the current level were set at a level between the ones they have available—for example, how brightly would the LED shine at Level 10? (Not as brightly as at Level 16, but brighter than at Level 8.)

STEP 3: ADDING COIL AND MAGNET TO THE EDU

1. Distribute Student Worksheet 2 (pp. 14 and 15) and the materials listed.
2. Instruct students to keep the circuit open until they test the circuit. Remind them to maintain the current level setting at 16.

CAUTION: Remind students that they may damage the LED beyond repair if they do not include the Current Controller in the circuit.

NOTE: You may wish to stop all activity once students have assembled the EDU with the coil and the magnet to instruct the whole class about the next steps. However, if your students can work independently, the activity will flow more smoothly if you allow teams to move on their own through the rest of Step 3 and all of Step 4, as soon as the coils, magnets, and rulers are added to the EDU. You can facilitate this activity by circulating around the room and instructing the teams as they are ready to move on.

3. After verifying that teams have working EDU models, ask students to explore what happens when the coil is included in the closed circuit, with and without the magnet inserted in the box. It is most interesting to observe what happens when the magnet is inserted in the box before students close the circuit.

NOTE: Students can close the circuit by simply, gently touching the alligator lead from the battery to the Current Controller rather than clipping it. A gentle touch will prevent the box from being jostled, thereby making the electrodynamic motion of the coil more noticeable.

3. Upon closing the circuits, students should observe that the coil moves forward or backward. They should also confirm that the coil moves only when two conditions are met: (1) current flows through the coil and (2) the coil is in the strong part of the magnet's field. (A third condition is also important, but the activity is not designed to highlight that one. The current and the magnetic field must not be parallel to one another.)

STEP 4 (OPTIONAL): CHANGE THE DIRECTION OF THE CURRENT

NOTE: In this activity, students will observe that changing the direction of the current changes the direction of the coil's movement, and that changing the direction of the magnetic field (by changing which pole is near the coil) also changes the direction of the coil's movement.

1. Remind students to keep the current level constant (at level 16). Facilitate student exploration as necessary: When all groups have used the EDU at Level 16, with variations on the connections and use of the magnet, briefly discuss everyone's findings.
2. Switch the alligator lead connections to the coil leads, with and without the magnet inserted. (The LED will light in all cases. If the magnet is inserted in the box or nearby, the coil will move in different directions when the connections are switched. If the magnet is not inserted in the box, the coil will not move at all.)
3. Turn the magnet around so the opposite pole faces out. (The LED will light in all cases. The coil's movement toward or away from the box will depend on which pole of the magnet is facing out.)
4. Try other variations as students suggest and as time permits. (Student suggestions might include waving the magnet near the coil while the circuit is on, holding the magnet near the coil in different orientations and at different distances or heights, or quickly opening and closing the circuit. Students may suggest exploring the effects of using different current levels, which is what they will do next!)

STEP 5: OBSERVE AND MEASURE VARYING LEVELS OF ELECTRIC CURRENT

A. EXPLORE ANY PATTERNS OR TRENDS THAT RESULT FROM VARYING LEVELS OF ELECTRIC CURRENT

1. Discuss and predict how the current level affects how far the coil moves. Ask students to think about how the coil motion might be related to the electricity level. (There are three basic possibilities: The coil motion will increase, decrease, or stay the same with increases in the current.) Try to get these three possibilities recognized in the discussion, even if students think one is more likely than the others.
2. Ask students to try different current levels, noting their qualitative observations.
3. Discuss the student observations in terms of trends. (Ex.: "The higher the current level, the greater the deflection.")

B. MEASURE THE MOTION OF THE COIL

NOTE *NOTE: The magnet should be inserted such that when the circuit is closed, the coil's motion is toward the box.*

1. Distribute the Student Worksheet 3 (p. 21) to all students.
2. Instruct students to systematically measure and record the motion of the coil for each of the five current levels.
3. Look at the EDU from the side of the box that has the ruler. The toothpick pointer attached to the coil's card should rest at the zero mark of the ruler.

NOTE *NOTE: The magnet should be inserted such that when the circuit is closed, the coil's motion is toward the box.*

4. When the coil moves, the toothpick pointer will point to higher numbers on the ruler to indicate the amount of deflection. Students will need to convert cm to mm or attend only to the mm markings on their rulers.

STEP 6: GRAPH AND INTERPRET THE RESULTS

A. GRAPH THE RESULTS

STEP 6
1. When teams have finished collecting the quantitative data, ask them to graph their results on Student Worksheet 3 (p. 21). You could also collect and graph the class data on a chalkboard.
2. When all team results have been recorded, make a class graph of the data. You can either graph each team's result or graph the average of all teams' data.

B. DISCUSS THE GRAPH AND HOW IT RELATES TO THE POSSIBLE TRENDS THE STUDENTS DISCUSSED

1. Ask students if they see a broad, sweeping trend. ("The greater the current, the greater the distance the coil moves.")
2. Is the relationship a doubling relationship, close to it, or something else?
3. How might the dots be connected—as a straight line, a curve, or as jagged line segments?

C. USE THE GRAPH TO DISCUSS SOME HYPOTHETICAL SITUATIONS

1. Pretend you had an electricity level controller that allowed you to set the levels at any whole number amount between 1 and 16. If you wanted to move the coil 7 mm, where would you set the controller?
2. How does understanding the pattern or trend of the data help us make this decision?
3. What distance would you expect level 3 to move the coil?

D. DISCUSS THE RELATIONSHIP BETWEEN THE CURRENT LEVEL AND THE LIGHT AND BETWEEN THE CURRENT LEVEL AND THE MOVEMENT OF THE COIL

1. How does having the data and the graph help us make a good prediction about how the system will work at different current levels, not just at Levels 1, 2, 4, 8, and 16, but also at the levels in between?
2. If you were responsible for figuring out how much electricity to use to get the coil to move a certain amount (ex. 10 mm), would you rather have just the visual observations you made, just the data you collected, just the graph, or a combination of some of these? Why?

3. What do the visual observations, the data we collected, and the graph all tell us about how the current level relates to the light emitted or the distance the coil moves? How do they tell us the same thing, but differently?

NOTE: If you have more time to give to this activity, you could more completely address data analysis as part of this lesson. After allowing student teams to work independently to collect the data, the class can share all its coil motion data. Then ask them to determine what values are typical for each current level. They might consider averaging data, but other options also exist—the most common value (mode), or even the middle value (median) might be more "typical" than the average. Looking at the data critically may provide an opportunity to consider when it seems appropriate to re-run trials when faulty data is suspected.

NOTE: The Sample Data Table and Graphing Template (p. 22) was collected by one team of students during the pilot test of this activity in Cambridge, MA. Note how nearly linear this graph is. Isn't it tempting to draw a straight line connecting the dots? But do we really know enough to do that?

We want to instill in students respect for the data and a cautious attitude in interpreting it, so before we "connect the dots," wait a moment. Think about this: When we connect the data points on this graph with straight line segments, we are thereby implying something about all the values along the line, i.e., about the intervening values where we did not collect data. We will be expressing an assumption about the movement of the coil at current levels where we did not test. Are these assumptions valid?

Moreover, how sure are we about our data points? It's pretty hard to measure the movement of that coil in millimeters! Do we want to base our curve on one set of data points? What is the best curve to represent the actual relationship? A smooth curve? A jagged set of line segments? Any sweep of your pen connecting these data will, in fact, show an approximation of the function that you believe exists.

We don't know enough about the subtleties of this system to give you an answer. That is precisely the value of gathering a lot of data in scientific explorations. Check out Extension 3 (p.11) to pursue this discussion a little further.

EXTENSIONS

1. To further develop this sense of trends, examine other relationships and compare them to the graphs and data you made for this unit. Simple relationships are the more M&Ms in a bag, the more it weighs; the more students in the room, the more shoes there are.
2. To further develop the idea that the relationship between the movement of the coil and the current is a reliable one and that every specific input has a specific output (that's a function), ask students to try to guess at which electricity level their partners are setting the circuit, based on how far the coil is moving.
3. As a more challenging extension, you could introduce "mystery" current controllers. Use the specific resistor levels on the right to create the corresponding current levels. Ask students to propose what they think the current level is, based on how far the coil moves when set at each mystery level.

The following commonly available resistors, used in a new Current Controller, will provide approximately the Current Levels indicated.

Resistance	Current Level
33 ohm	13.5
47 ohm	11
68 ohm	9
100 ohm	7
150 ohm	5
330 ohm	3

4. Curious about those colored stripes on the resistors? They actually are a code that tells the resistance of the resistor. Danny Goodman, one of the inventors of HyperCard, has a resistor calculator on his web site. You can enter the colors you see on a resistor and find out the resistance. Check it out at **http://www.dannyg.com/javascript/res2/resistor.htm**

Color Coding of Common Resisitors

Resistance in ohms	First stripe	Second stripe	Third stripe	Fourth stripe
22	Red	Red	Black	Gold
33	Orange	Orange	Black	Gold
47	Yellow	Violet	Black	Gold
68	Blue	Gray	Black	Gold
82	Gray	Red	Black	Gold
100	Brown	Black	Brown	Gold
150	Brown	Green	Brown	Gold
180	Brown	Gray	Brown	Gold
220	Red	Red	Brown	Gold
330	Orange	Orange	Brown	Gold
470	Yellow	Violet	Brown	Gold
1000	Brown	Black	Red	Gold

The chart shows the color coding on some common resistors. See if you and your students can figure out how the code works. Orient the resistor so that the gold stripe is to the right-hand side of the resistor. Nearly every resistor you come across will have a gold stripe. A very few may have a silver stripe. If so, treat it as if it were gold.

STUDENT WORKSHEETS

STUDENT WORKSHEET 1: BUILDING THE EDU PLATFORM WITH LED AND WITHOUT COIL

MATERIALS PER TEAM

corrugated cardboard
3 double-headed alligator clip leads (small toothed)
2 fresh D cell batteries
double-cell battery holder
1 LED (light emitting diode)
tape (cellophane or masking)
1 prepared Current Controller
wire strippers and sharp scissors
1 copy of EDU Circuit Without Coil (Figure 3, p. 18)

STEP 1

PREPARE THE PLATFORM

1. Refer to EDU Circuit Without Coil (Figure 3, p. 18).
2. Use scissors to cut two, 2-cm slits in the front edge of the corrugated cardboard that will serve as the platform. One slit should be 4 cm from the right edge of the cardboard, and the other should be 1 cm from the right edge.

STEP 2

PREPARE THE LED

1. The two metal pieces sticking out of the LED are its leads. Gently bend the leads apart so they look like the illustration (Figure 3, p. 18).
2. Tape the LED onto the cardboard sheet in approximately the position shown.

STEP 3

MAKE ELECTRICAL CONNECTIONS

1. Place the D cells in the battery holder, being careful to orient them in the holder as shown in the diagram (Figure 3, p. 18).
2. Use the wire strippers to strip about 1 cm of the plastic insulation off the ends of the battery holder leads. Remove only about 1 cm of insulation.
3. Tape the battery holder in place on the platform.
4. Attach one clip of a double-headed alligator lead to the red wire coming from the battery holder. (This is the positive battery terminal.) Later, you will attach the other end of this lead to the Current Controller.
5. Attach one clip of another double-headed alligator lead to the black wire coming from the battery holder (negative battery terminal).
6. Attach the other end of this lead to the SHORT lead of the LED.
7. Attach one clip of a third double-headed alligator lead to the LONG lead of the LED.
8. Attach the other end of this lead to the right-hand side of the Current Controller at Level 16. (Later, you will be able to try other levels.)

STEP 4

TEST CONNECTIONS

1. To close the circuit, touch the free clip of the lead coming from the red wire on the battery holder to the free end of Current Controller Level 16. The LED should illuminate. If not, try troubleshooting:
   a. Trace the circuit path with your finger; are there any openings or places where connections are not made?
   b. Are your connections tight?
   c. Make certain that the LED leads are not touching each other.
   d. Make sure that the clip attached to each LED is not touching the other lead or the other clip.
   e. An LED will not light if you attach the wrong lead from the battery to the LED leads.
   f. Make certain that the black (negative) terminal wire goes to the short LED lead.
   g. If all else fails, check the LED and batteries by inserting them into a circuit that you know is working.
2. When you know the circuit is in working order, detach one connection to open the circuit.
3. Tape the components of your circuit to the platform so that it stays tidy (and easy to work with).
4. Make sure you leave enough loose wire to make connections, but tape most of the excess wire.

STUDENT WORKSHEET 2: ADDING COIL AND MAGNET TO EDU

STEP 1

STEP 1: MAKE THE COIL

1. In your group, decide how to divide the work so you can finish as quickly and with as much team participation as possible.
2. Pull about 45 cm (18 in.) of wire off a wire roll. Do not cut.
3. Position the film can at the 45th cm of this wire so that you will be able to wrap more wire from the roll directly onto the film can.
4. Hold the wire in place with your thumb.
5. Allow the 45 cm of wire to dangle.
6. Wrap wire onto the film can from the roll. Count 50 wraps.

NOTE

NOTE: As you wrap, use your thumb to hold down any wire already on the film can.

7. After 50 wraps, unroll an additional 45 cm or so of wire from the wire roll and cut.
8. Gently wiggle and pry the wrapped coil off the film can.

CAUTION

CAUTION: The wire can spring off the film can and become tangled. Do not use anything sharp to remove the wire because you may nick the red enamel insulation on the wire and cause a short circuit.

9. Holding the freed coil in your hands so it does not unwind, have someone tape the coil to keep it from unwinding. Wrap tape tightly around the coil (see Figure 4, p. 19).

MATERIALS PER TEAM

The prepared EDU platform with LED circuit
box
1 additional double-sided alligator clip lead
strip of manila folder, 3 cm x 16 cm
toothpick
mm ruler
magnet wire
35-mm film cannister
tape
cow magnet
sandpaper
scissors
Copies of
Overview of EDU Setup (Figure 1, page 16)
EDU Circuit with Coil (Figure 2, page 17)
EDU Circuit Without Coil (Figure 3, page 18)
Coil Mounted on Manila Folder (Figure 4, page 19)

STUDENT WORKSHEET 2, cont.

STEP 2

STEP 2: MOUNT THE COIL ONTO A STRIP OF MANILA FOLDER

1. Refer to Figure 4, Coil Mounted on Manila Folder (p. 19).
2. Place a 3-cm x 16-cm strip of manila folder in front of you.
3. Position the coil so that it is about 1 cm away from the bottom of a short edge of the manila strip.
4. Tape one long lead of wire from the coil along one 16-cm edge of the platform. Tape the other lead to the other 16-cm edge. There should be excess wire extending from the strip.
5. Tape a toothpick at a 45 degree angle to the bottom of the manila card so that it extends diagonally from the bottom right-hand corner of the card.
6. Sand about 3 cm of each end of wire so that you remove the shiny enamel coating, which is the insulation. To do this, pinch the end of the wire in a folded piece of sandpaper and gently pull the paper across the wire.

STEP 3

STEP 3: POSITION THE MAGNET, RULER, COIL, AND PLATFORM

1. Refer to Overview of EDU Setup (Figure 1, p. 16).
2. Insert the magnet into the hole in the front side of the box. Make sure only 4 cm of it sticks out.
3. Place the EDU platform on top of the box so that the front (side with the slits) faces you.
4. Insert the wire leads from the coil into the slits so that the toothpick faces off to the right.
5. Adjust the position of the coil (by pulling on the wire leads and by moving the platform forward and back) until the coil is just at the tip of the magnet and so that the magnet is centered in the coil ring.
6. Tape the platform in place on the box top, being careful not to slide it around.
7. Tape the coil leads onto the platform, being careful not to tug on them. You don't want the coil position to change! Leave enough wire untaped so that you will be able to make electrical connections with other clips in the circuit.
8. Find the lead that connects the LED to the Current Controller. Detach its clip from the Current Controller and attach it to the right coil lead.
9. Clip an additional double lead to the left coil lead.
10. Attach the other clip of this "new" lead to the Current Controller.
11. Check to be sure that the coil is still hanging in the proper position at the tip of the magnet with the magnet centered inside the coil.
12. When you are sure this arrangement is set, tape the ruler to the side of the box so that about 4 cm extends off the box towards the front. Adjust the ruler so that the toothpick points to the zero point on the ruler. The ruler should be just below the tip of the toothpick.
13. Once the ruler is properly positioned, tape it in place. You may need to untape the toothpick and tape it in a slightly different position to get it to line up with the zero point on the ruler.

FIGURE 1: OVERVIEW OF EDU SETUP

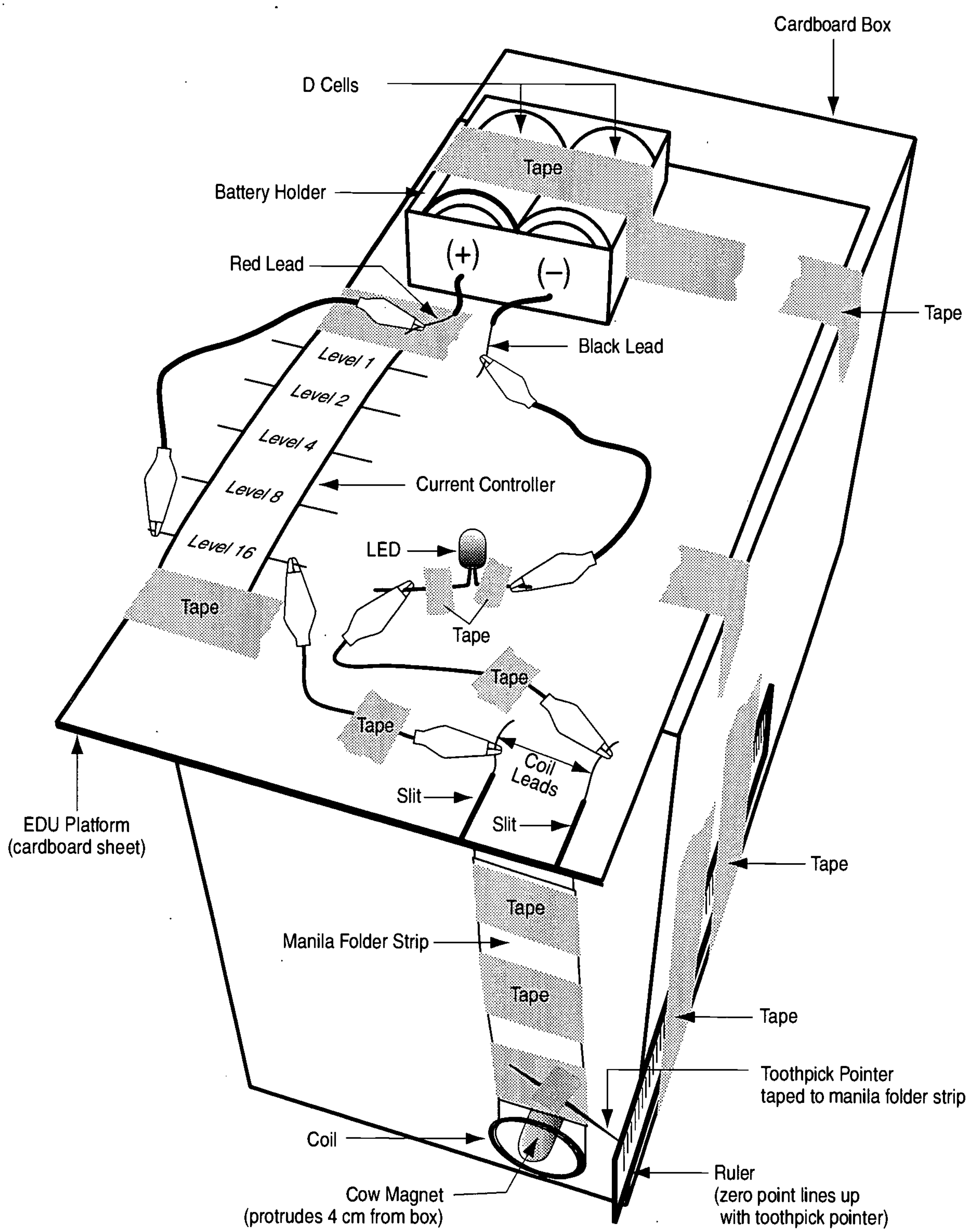


FIGURE 2: EDU CIRCUIT WITH COIL

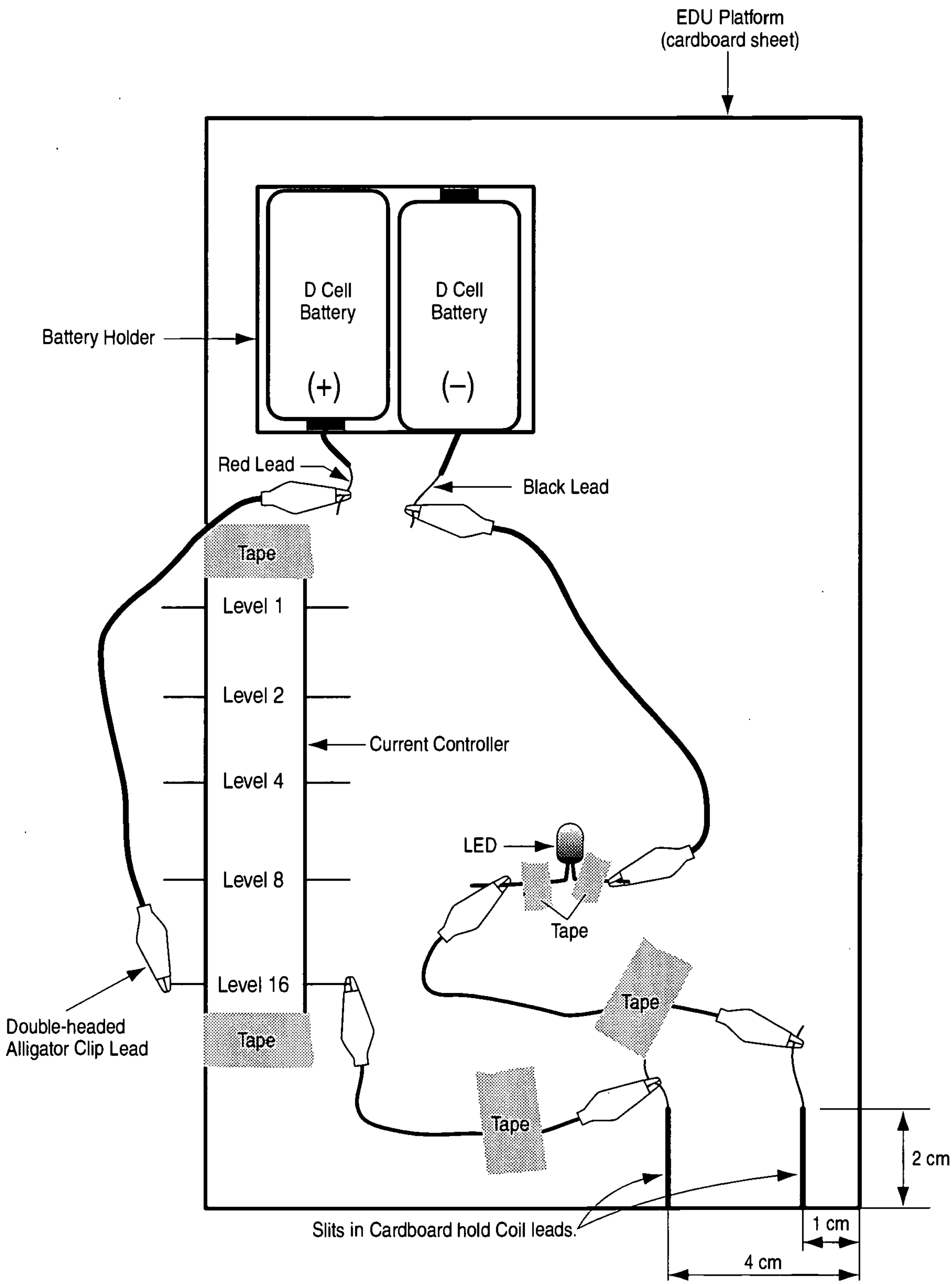


FIGURE 3: EDU CIRCUIT WITHOUT COIL

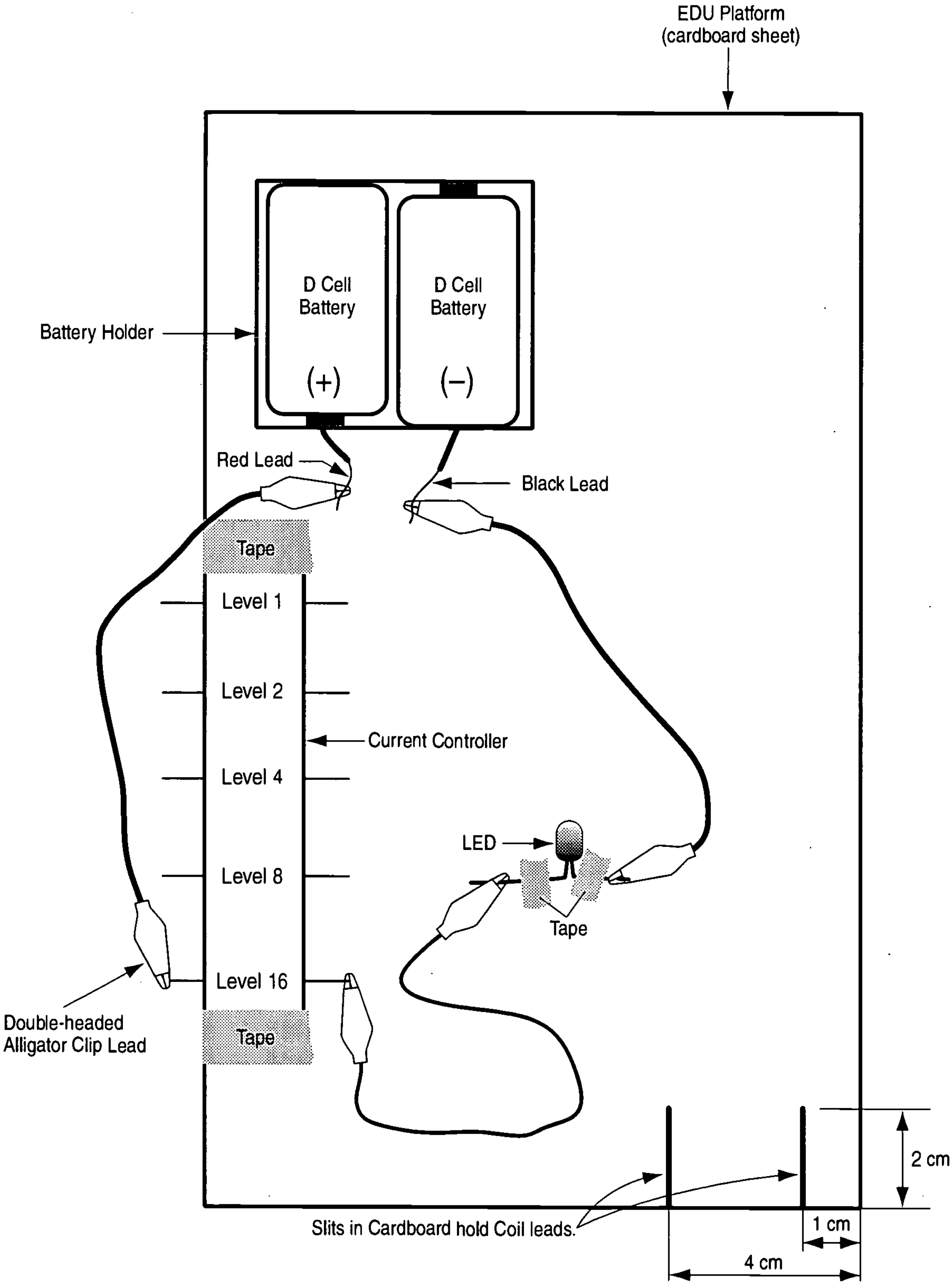


FIGURE 4: COIL MOUNTED ON MANILA FOLDER

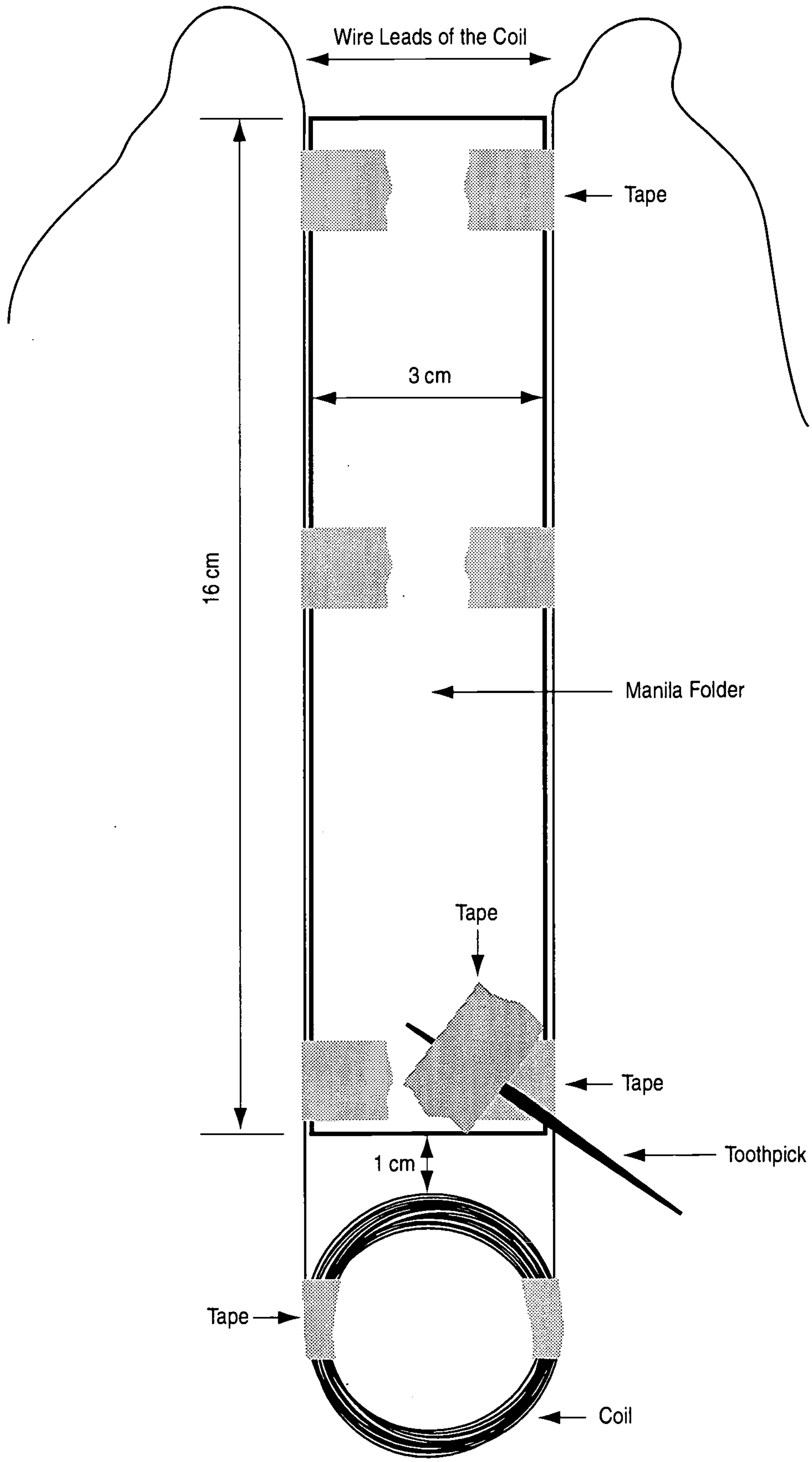


FIGURE 5: CURRENT CONTROLLER TEMPLATES

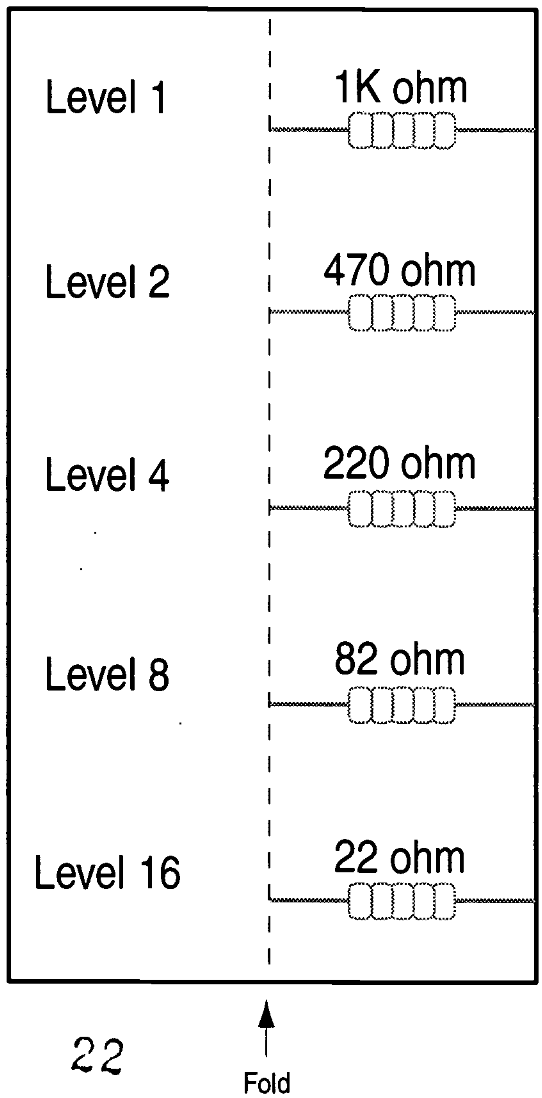
How to Build the Current Controller

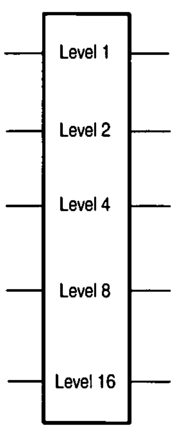
Materials:
Scissors
Tape
Resistors
One current controller template for each student team

For each current controller you need:
1 22 ohm resistor
1 82 ohm resistor
1 220 ohm resistor
1 470 ohm resistor
1 1000 ohm (1K ohm) resistor

Instructions:
1. Cut out each template on the solid lines.
2. Fold each template on the fold line, so the writing is on the outside.
3. Tape the resistors in place on the back of the template in the positions shown. (Note: the resistors extend beyond the edges of the template.)
4. If you think seeing the resistors will distract or confuse the students, cut a piece of paper the same size as the back of the template and tape it over the resistors to cover them or cover them in some other way.

Resistor





Front View of Completed Current Controller

STUDENT WORKSHEET 3: DATA TABLE AND GRAPHING TEMPLATE

Data Table	
Current Level	Coil Movement (rounded to nearest mm)
1 (Lowest current)	
2	
4	
8	
16 (Highest current)	

1. Did you discover a rule or a trend? ☐ Yes ☐ No

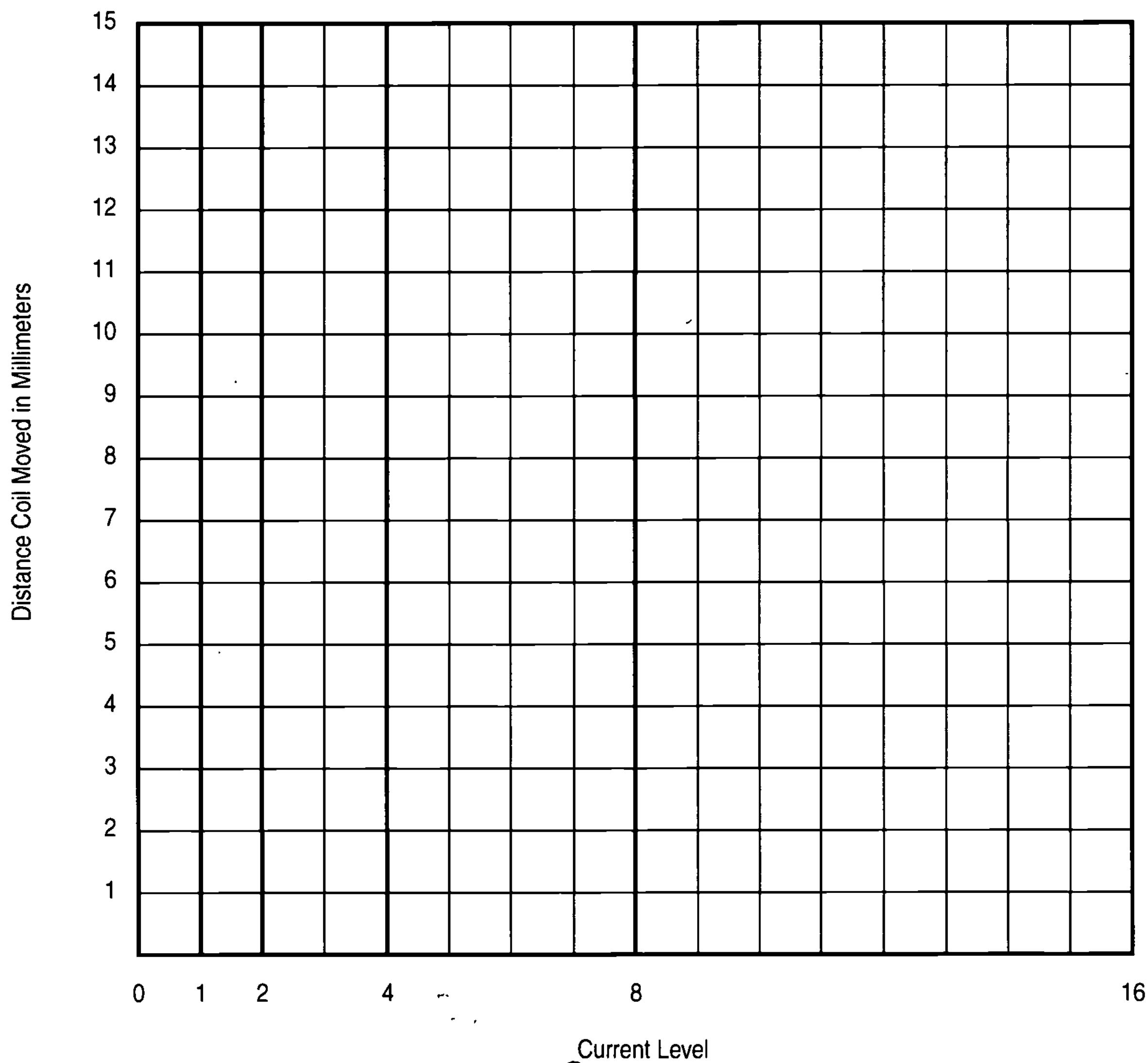
2. If yes, what was it?

____

____

____

3. Graph your data below.



SAMPLE DATA TABLE AND GRAPHING TEMPLATE

Data Table	
Current Level	Coil Movement (rounded to nearest mm)
1 (Lowest current)	1
2	2
4	3
8	6
16 (Highest current)	15

1. Did you discover a rule or a trend? ☐ Yes ☐ No

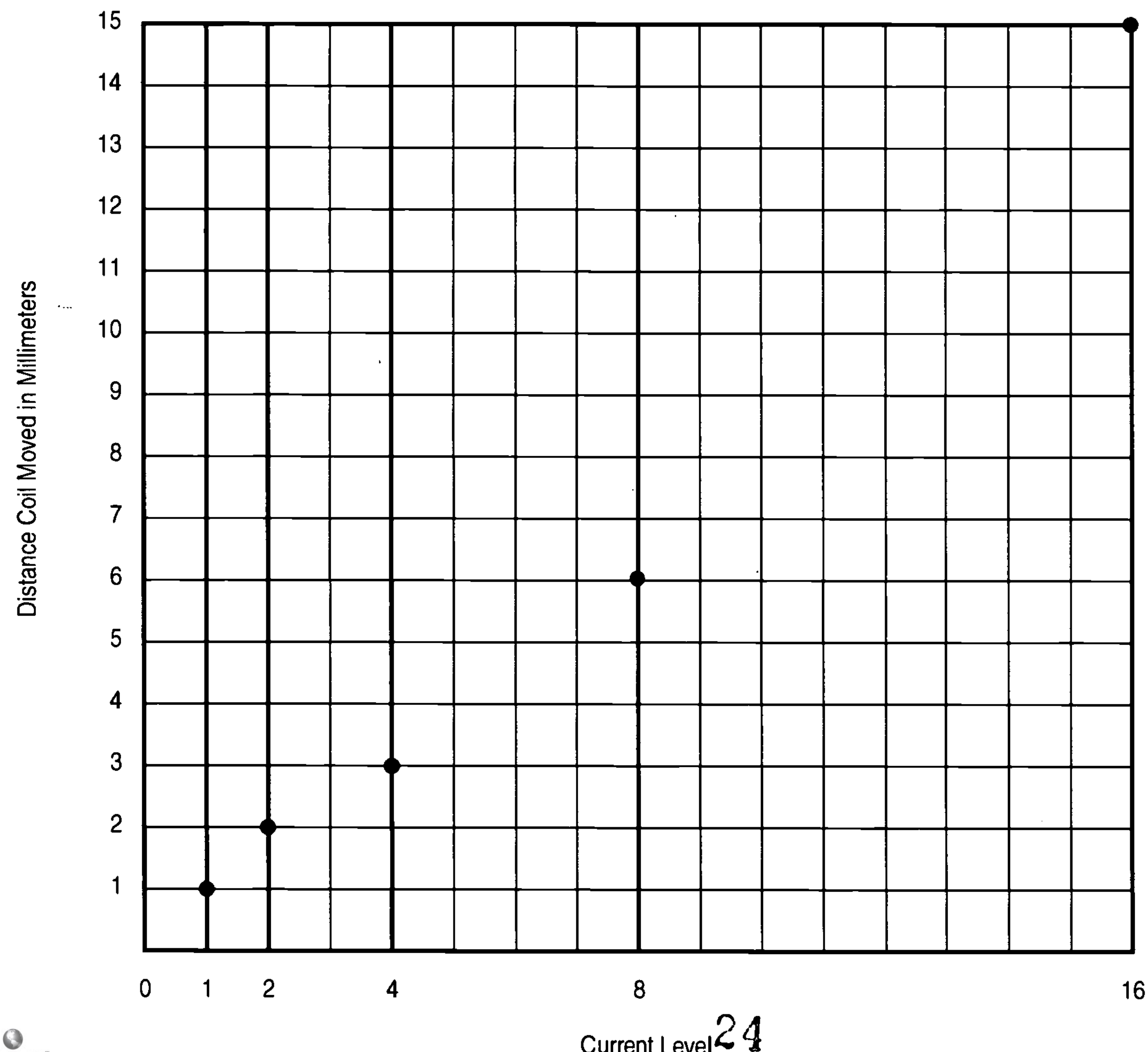
2. If yes, what was it?

____

____

____

3. Graph your data below.



STUDENT CUE CARDS

Jose Perez, Launch Assist Project Manager, Kennedy Space Center

1. What kind of test did they use? ____________________

2. Were there any patterns in the results? ____________________

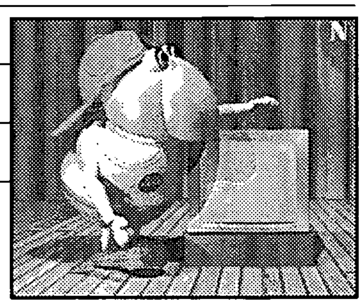
3. What kind of graph resulted from the data? ____________________

Leslie Curtis, Engineer, Marshall Space Flight Center

1. How was algebra used to find the solution? ____________________

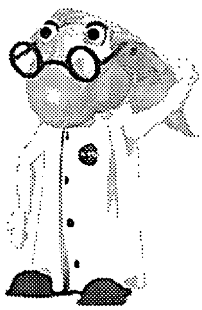
2. How are arrays used in algebra? ____________________

3. What algebraic equation shows that voltage is related to current? ____________________



THE WEB ACTIVITY

THE ACTIVITY



To access IPPEX, visit Norbert's lab, **http://connect.larc.nasa.gov/wired/lab.html**

The Internet Plasma Physics Education eXperience (IPPEX) is an interactive on-line activity developed by the Princeton University Plasma Physics Laboratory, Princeton, New Jersey. IPPEX has created several interactive physics modules, including one on electricity and magnetism. This module will introduce many of the basic concepts involved with electricity and magnetism, such as static charge, moving charge, voltage, resistance, and current. This site combines multimedia with built-in interactive exercises to help students better understand the concepts of electricity and magnetism. For example, IPPEX invites students to rub a balloon on a wool sweater to learn about static electricity, and later, to manipulate slider bars to see what happens to similar static charges between balloons. Students are also introduced to the concept of what makes an electrical circuit and to the relationships between magnetic fields and electricity.

To access IPPEX, visit Norbert's lab **http://connect.larc.nasa.gov/wired/lab.html.** Norbert's lab contains links to additional on-line resources and a link to *Career Corner*, featuring researchers and NASA CONNECT team members. New this season is the NASA CONNECT *Lab Manager.* The *Lab Manager* offers assistance to teachers who would like to get the most from the site.

NATIONAL STANDARDS

TECHNOLOGY STANDARDS

- Develop positive attitudes toward technology uses that support lifelong learning, collaboration, personal pursuits, and productivity.
- Use technology tools to enhance learning, increase productivity, and promote creativity.

SCIENCE STANDARDS

- Light, heat, electricity, and magnetism
- Transfer of energy

MATHEMATICS STANDARDS

- Use mathematical models to represent and understand quantitative relationships.
- Analyze change in various contexts.
- Develop and evaluate inferences and predictions that are based on data.
- Apply and adapt a variety of appropriate strategies to solve problems.

INSTRUCTIONAL OBJECTIVES

Students will
- use critical thinking skills and problem-solving skills to gain an understanding of electricity and magnetism.
- use technology to further their problem-solving skills and understanding of electricity and magnetism.

RESOURCES

BOOKS, PAMPLETS, AND PERIODICALS

Challand, Helen J., *Experiments with Magnets.* 1986: Canada and USA, Ragensteiner Publishing Enterprises, Inc. Introductory level explorations of magnets and magnetism.

Hewitt, Paul G., *Conceptual Physics.* 1985: Boston, Little Brown and Company. (A good teacher resource, this is a physics textbook written in an accessible style.)

Scientific American, Spring 1999 Special Edition. *Scientific American Presents the Future of Space Exploration: A Guide to the Voyages Unveiling the Cosmos.* Includes an extensive section highlighting the cutting edge of space flight technology and research. (ISSN 1048-0943), Volume 10, Number 1, Spring 1999. Published quarterly by Scientific American, Inc., 415 Madison Avenue, New York, NY 10017-1111.

Space Transportation: Past, Present and Future. CD-ROM Reference Number 400.1-29. To order, contact NASA CORE 440/775-1400; email nasaco@leeca.org or visit the website: http://core.nasa.gov

Space Basics: An introduction to the physics of orbiting satellites. NASA Liftoff to Learning Series, Videotape Reference Number EV-1997-07-010HQ. (To preview online or order, contact NASA CORE 440/775-1400; email nasaco@leeca.org or visit the website: http://core.nasa.gov)

Tethered Satellites Part II: Electrical Circuits in Space/The Electrodynamics of the Tethered Satellite. NASA Liftoff to Learning Series Videotape Reference Number EV-1997-07-011HQ. Describes how the current is produced in a space tether used for propulsion. (To preview online or order, contact NASA CORE 440/775-1400; email nasaco@leeca.org or visit the website: http://core.nasa.gov)

Vecchione, Glen, *Magnet Science.* 1995: New York, Sterling Publishing Co., Inc. Activities and information about magnetism for middle school students and beyond.

WEB SITES

NASA Earth-to-Orbit Engineering Design Challenges: Electrodynamic Propulsion. Pending publication. A 2-3 week design challenge about electrodynamic propulsion. **http:///eto.nasa.gov**

Brief introduction to MagLev with links to other resources on this topic.
http://kids.msfc.nasa.gov/News/2000/News-MagLev.asp

Electricity Misconceptions In K-6 Textbooks by William J. Beaty. Resource for teachers, addressing helpful and not-so-helpful ways in which "electricity" is described and demonstrated for students.
http://www.amasci.com/miscon/eleca.html#electron

An accessible, simply written article introducing the idea of using tethers in space.
http://liftoff.msfc.nasa.gov/academy/TETHER/tethers.html

Description of the Pro-SEDS mission in the form of a NASA Science News article, *Plugged Into Space.*
http://www.science.nasa.gov/newhome/headlines/ast15oct98_1.htm

Historical look at William Gilbert, later physician to Queen Elizabeth I of England and his pioneering study of magnetism that gave the first rational explanation to the ability of the compass needle to point north-south.
http://www-spof.gsfc.nasa.gov/earthmag/demagint.htm