

Vernier Mars Challenge

With LEGO® MINDSTORMS® Education EV3



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Using this Guide

This curriculum guide offers an opportunity to introduce students to the physical concepts of electricity and magnetism through exciting hands-on robotics activities. By coupling robotics design with NASA's space program, students will gain an understanding of scientific principles in a real world application. This guide was written for teachers with the Educator version of LEGO's EV3 robotics system. It is intended to be used for a week-long summer camp, a STEM classroom module, or an after-school club.

The Course Description immediately following this section can be copied into your promotional materials when advertising your summer camp. Detailed descriptions of recommended activities are supplied for each unit, as well as optional extensions for early finishers. Teachers should feel free to select those activities that are most relevant to their classroom situations. Suggested time allotments for each activity are approximations based on a 2–4 hour unit and may need adjustment based on the age, ability, and past experience of your students. If possible, students should be given the option of working alone or with a single partner.

It is recommended that you have students build the *EV3 Educator Vehicle – Driving Base* for their initial robots in order to give them some experience reading and interpreting a CAD (computer-aided design) drawing. Building instructions for the *EV3 Educator Vehicle* can be found in the Robot Educator section of the EV3 software Lobby. If you are using the commercial version of the software, you can find the building instructions for the *EV3 Educator Vehicle* online.

Building guides for the additional robotic attachments used in each activity are provided in *Appendix C*. If time permits, you are encouraged to use those guides as demonstration examples only and let students use their imagination to build their own designs for each attachment. Communication between team members will be greatly improved if students know the proper name and function of key building components. Be sure to take time in the beginning to discuss brick management rules and naming conventions for projects, programs, and experiments, especially if the EV3 Bricks will be used by more than one student.

This book will not go into detailed programming instruction but will assume that you have some basic knowledge of the EV3 software or have access to one of the many reference books available from local book stores. Sample programs will be given for all activities to aid you in your instruction, but it is recommended that you encourage students to be creative and write their own programs to solve each challenge.

Teachers are asked to adopt a *hands-off* policy when helping students—in other words, try to refrain from touching individual robots or computer keyboards. Instead, give your students verbal tips when asked for assistance and encourage students to try it on their own.

Above all, take a deep breath, relax, and enjoy yourself. There will be times when you will not have all the answers. Generate an atmosphere that honors the maxim, “*if at first we don't succeed, try, try again.*” Remember, the goal of this curriculum should be to show students that engineering is fun.

Course Description

In 2012, NASA sent the *Curiosity* rover to Mars to search for signs of past life in magnetic rocks. Recently, two astronauts were stranded on Mars while attempting a routine mission to service the rover. A sudden storm has covered their solar panels in dust and most of their backup batteries have run down. Your team of robotics specialists has been brought in to build a robot to retrieve the stranded astronauts, remove the dust from the solar panels, and find the magnetic rocks scattered near the base station. In addition, you will learn to use a voltage probe and magnetic field sensor as you build a solar tracker, a battery tester, and a robotic compass.

Overview

- **Day 1: Magnets**
Learn how a magnet works
Measure the magnetic strength of various magnets
Build a robotic magnet detector
- **Day 2: Batteries**
Learn how a battery works
Measure the electric potential of various batteries
Build a battery tester
- **Day 3: Compasses**
Learn how a compass works
Graph the magnetic field around a bar magnet
Build a robotic compass
- **Day 4: Solar Panels**
Learn how a solar panel works
Measure the electrical output of a solar panel at different angles
Build a solar tracker
- **Day 5: Martian Challenge**
Learn how to write pseudo code
Strategize a time-based solution
Build a multi-tasking Martian rover

Magnets

Task

Build a robot that will play a sound when it drives past a magnet.

Objectives

- Investigate the behavior of a magnet
- Learn how to use a magnetic field sensor
- Take sensor measurements with the EV3 Brick
- Build a robot from a CAD drawing
- Program a robot to detect a magnet

Vocabulary

- attract
- magnet
- magnetic field
- neodymium
- North Pole
- repel
- South Pole
- Tesla

Materials (for each team)

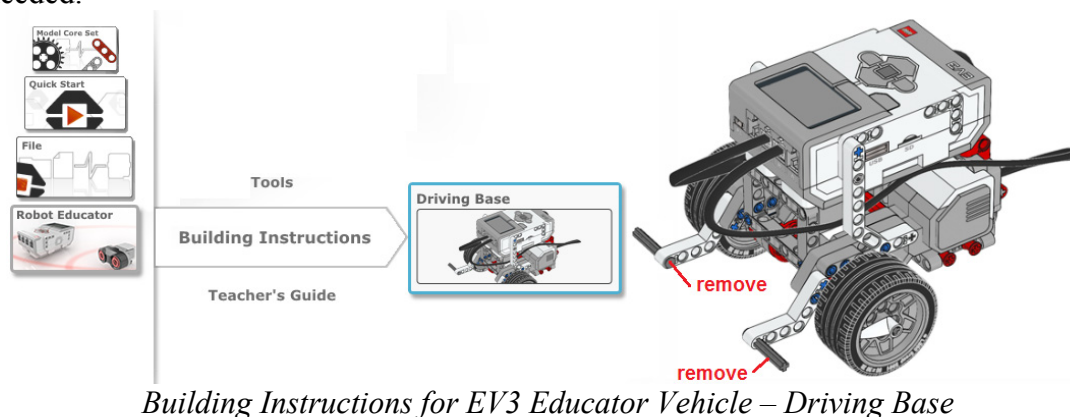
- LEGO robotics kit
- Magnetic Field Sensor (Vernier MG-BTA)
- NXT Sensor Adapter (Vernier BTA-NXT)
- 2 bar magnets
- paper clips (plastic and metallic)
- neodymium disc magnet
- dark tape (ie. black electrical tape or blue painters tape)
- engineering notebook
- pencil

Preparation

1. Import the Vernier Sensor Block into the EV3 software on each computer using the directions found in *Appendix B*.
2. Check that each EV3 Brick has the latest firmware and is fully charged (the procedure for updating the firmware can be found in the Tools menu). If the EV3 Bricks have been used before, you may want to erase all previous projects.
3. Duplicate one copy of the engineering notebook (found in *Appendix K*) for each student.
4. Set the switch on all Magnetic Field Sensors to the low amplification setting (6.4 mT).
5. You will be using neodymium disc magnets for this task. Lay out a line on the floor approximately 1 meter long with dark tape. Be sure the line is away from all metal objects. When students are ready to test their robots, randomly place 3 disc magnets along the line at

least 20 cm apart to avoid attracting each other. Tip: Glue each magnet inside a LEGO brick. They will be easier to see, and they will not pinch fingers if they attract one another.

- Optional: Build the *EV3 Educator Vehicle – Driving Base* to use as a demonstration example. You can find the building instructions in the Robot Educator section of the EV3 software Lobby. Remove the 4M cross axles from the front of the robot, as they will not be needed.



Building Instructions for EV3 Educator Vehicle – Driving Base

- Optional: Build a holder for the Magnetic Field Sensor so that it can be mounted onto the side of the robot. You can use the instructions in the *Side Sensor Holder* building guide found in *Appendix C*.

Order of Activities

- Give a brief overview of the upcoming activities in this course. (5–10 min)
- Describe the role of an aerospace engineer. A career overview on aerospace engineering is provided in *Appendix I*. Ask the students what they know about Mars and the NASA space program. Facts about Mars can be found in *Appendix H*. Explain why more effort is put into exploring Mars than any other planet. (10–15 min)

Space Science Extension: Have students create a timeline of significant events in space exploration. What inventions that we use today were first discovered as part of the space program?

- Explain the concept of magnetism. Let students examine their bar magnets and record their observations in their engineering notebooks. Discuss what causes some parts of the magnets to attract and some to repel. (5–10 min)
- Let students observe the behavior of their magnets when brought near a few paper clips (both plastic and metallic). Have them make predictions about the physical properties that cause an object to be attracted to a magnet. (5–10 min)
- Have students test the relative strength of their magnets by making a paperclip chain. Hold onto one end of a magnet and stick a paper clip to the other end of the magnet. Touch another paper clip to the end of the first paper clip to start a chain. Keep adding paper clips until no more paper clips stick to the chain. (10–15 min)

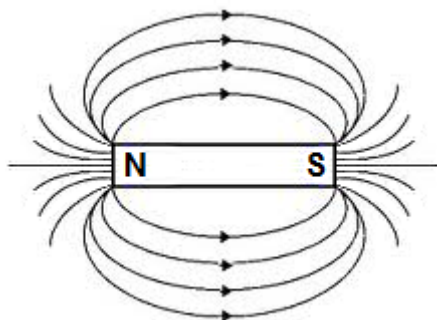
Physical Science Extension: Have students build an electromagnet with a wire-wrapped nail and 9-volt battery. Explore the relationship between the number of wire turns and the length of a paperclip chain that can be picked up by the electromagnet.

- Let students conduct a magnetic scavenger hunt. Have them test the behavior of various objects around the room when brought near their bar magnets. (*Warning: Do not use magnets near computers, cell phones, CDs, credit cards, and other electronic devices as this could disrupt the operation of these devices.*) Discuss the results of their observations and why objects did or did not attract when they thought the opposite would be true. (10–20 min)

7. Demonstrate how the Magnetic Field Sensor works. Have students write a program to measure the magnetic strength of their neodymium disc magnets. Discuss any differences in sensor readings from the top face versus the bottom face of the disc. (15–25 min)
Robot Educator Tutorial: If your students are not familiar with programming for the EV3 Brick, have them work through the Programming tutorial in the Quick Start section of the EV3 software Lobby. Make sure they know how to download and run programs on the EV3, as well as how to abort a running program. You might also wish to have them work through Tutorial #8, *Text*, in the Beyond Basics section of the Robot Educator. This tutorial demonstrates how to display real-time sensor values.
8. Have students build the *EV3 Educator Vehicle – Driving Base* according to the Building Instructions section of the Robot Educator. Let teams work at their own pace giving verbal guidance only when asked. (25–50 min)
9. Have students design and build a holder for the Magnetic Field Sensor similar to the model in the *Side Sensor Holder* building guide so that it can be mounted to the side of the robot. Use small rubber bands to secure the sensor to the holder. (15–30 min)
10. Have students write a program to command the robot to drive forward and play a sound every time it passes a magnet. (20–45 min)
Robot Educator Tutorial: This activity requires that the robot play a sound whenever it detects a magnet. If your students need a little additional programming instruction, have them work through Tutorial #3, *Switch*, in the Beyond Basics section of the Robot Educator. This tutorial teaches students how to use the Switch block to make sensor-based decisions.
11. **Challenge for Early Finishers:** Place three paper cups in a line on the floor. Randomly hide one neodymium disc magnet under one of the cups. Have students modify their programs to make the robot drive by the three cups and return to the one that is hiding the magnet. Use data from the rotation sensor to return to the correct position.

Background

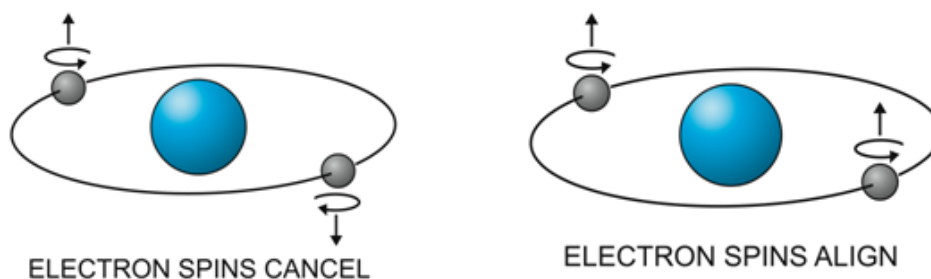
A *magnet* is an object that can attract certain metals such as iron, nickel, or cobalt. The two ends of a magnet, called the north pole and the south pole, exert the strongest force. When the north pole of one magnet is brought near the south pole of another magnet, the two magnets are attracted to each other. However, when two like poles are brought near each other (i.e., north and north or south and south), they repel each other. The forces of attraction and repulsion are present because of a magnetic field that completely surrounds the magnet. The *magnetic field* is an invisible area defined by magnetic lines of force that extend out from the north pole and then curve back into the south pole. The magnetic field is strongest near the poles because the field lines are more concentrated there.



Magnetic field lines around a bar magnet

What causes some materials to be magnetic, but not others? Magnetism is present in all materials but at such low levels that it is not easily detected. Negatively-charged electrons that spin around

inside atoms create small *magnetic moments*. You can think of the spinning electrons like the teacup ride at the amusement park. In non-magnetic objects, these electrons spin in opposite directions, cancelling each other out; but in ferromagnetic materials, the electrons spin in the same direction.



Electron paths for non-magnetic and ferromagnetic materials

An iron nail has a strong magnetic moment, but it is not a natural magnet. The nail contains billions of tiny magnets arranged in random clusters called *domains*. To make a nail into a magnet, you have to force its magnetic domains to line up in the same direction. There are three ways this can be done. All of these methods will produce a temporary magnet that should be able to pick up a few paper clips.

- Rub one end of a bar magnet down the length of the nail at least 20 times in the same direction. The more you rub, the stronger it becomes.
- Hold the nail against the edge of a brick with a pair of pliers so that the tip is pointed toward the Earth's North Pole. Strike the nail several times with a hammer to force the domains to line up.
- Wrap a length of insulated wire (approximately 1 meter long) around the nail. Connect the ends of the wire to the terminals of a 9-volt battery. When the electrical current flows through the wire wrapped around the iron nail, it creates what is known as an *electromagnet*. Electromagnets are very useful because you can turn their magnetic fields on and off.

Fun Fact

NASA engineers are using electromagnets to design a new propulsion system for launching spacecraft. This new system is similar to the *Flight of Fear* roller coaster at Kings Island Amusement Park or the magnetic levitating trains in Japan. Electromagnetic propulsion systems use strong electrical impulses to attract or repel magnetic fins attached to the space vehicle. When the system is activated, the space vehicle is levitated above electromagnetic rails and then propelled into orbit at speeds of over 600 mph. This cutting edge technology significantly reduces the cost of space missions by reducing or eliminating the amount of rocket fuel previously used to launch vehicles into space.

Sensor Notes

You can use the Vernier Magnetic Field Sensor to investigate the magnetic field around a magnet. The sensor measures the component of the magnetic field that is perpendicular to the white dot on the tip of the sensor. The reading is positive when the white dot is pointed toward a magnetic south pole and negative when pointed toward a north pole. Magnetic field measurements are displayed in units of milliTesla (mT).

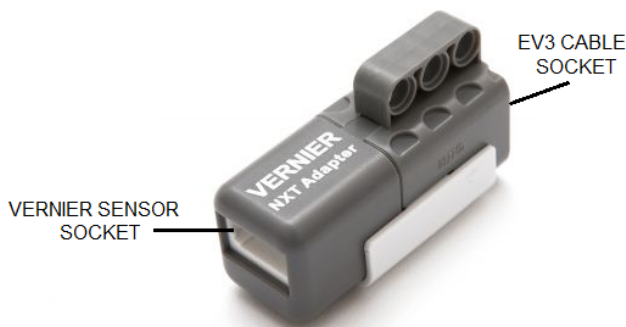


Vernier Magnetic Field Sensor

The sensor has two amplification settings that are selectable by a switch on the side of the sensor's shaft. The low amplification setting (6.4 mT) is used to measure relatively strong magnetic fields around permanent magnets as used in this activity. The high amplification setting (0.3 mT) is used to measure the weaker magnetic field of the Earth as used in Activity 3.

You can rotate the tip of the sensor to measure fields that are parallel or perpendicular to the shaft of the sensor. This feature comes in handy when mounting the sensor onto the robot. Both the side-mounted and front-mounted sensor designs (found in *Appendix C*) require that you bend the tip of the sensor at a 90° angle so that it is pointing away from the robot.

The Vernier NXT Sensor Adapter allows you to connect over 30 different Vernier sensors (including the Magnetic Field Sensor) to any port on the EV3 Brick. The adapter is slightly larger than the LEGO gyro sensor and includes a LEGO EV3 cable socket on one end and a Vernier BTA sensor socket on the other end. Vernier sensors do not have auto-ID capability when first plugged into the EV3 Brick, but are easily configured from the drop-down menus in the Switch, Loop, Wait, and Sensor blocks.

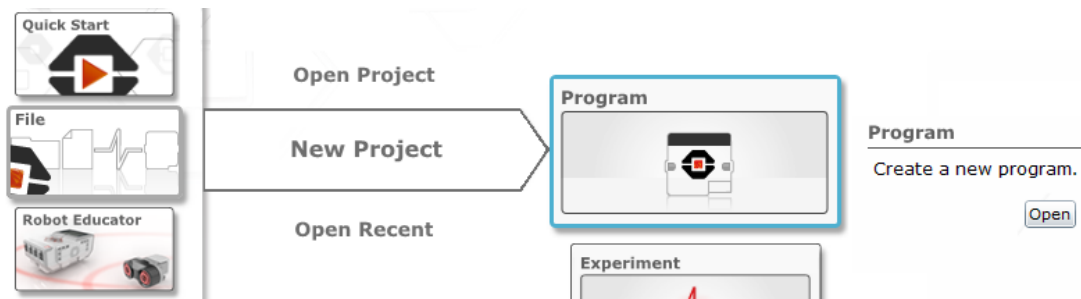


Adapter for connecting Vernier sensors to the EV3 Brick

Programming Basics

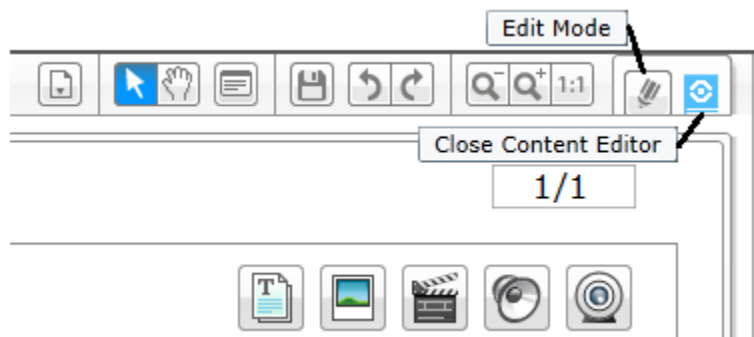
Every time you open the EV3 software you start out in the Lobby. The *Lobby* is where you can find tutorials, building instructions, and a teacher's guide. If your students have little or no programming experience, you may want to have them run through the Quick Start Programming tutorial before writing their own programs.

When you start your first program the EV3 software automatically creates a Project. *Projects* allow you to group together the programs and experiments you create during this unit. It is a great management tool, especially when students from different teams are sharing the same computer. Simply click the Open button to create a new project and launch the programming canvas.



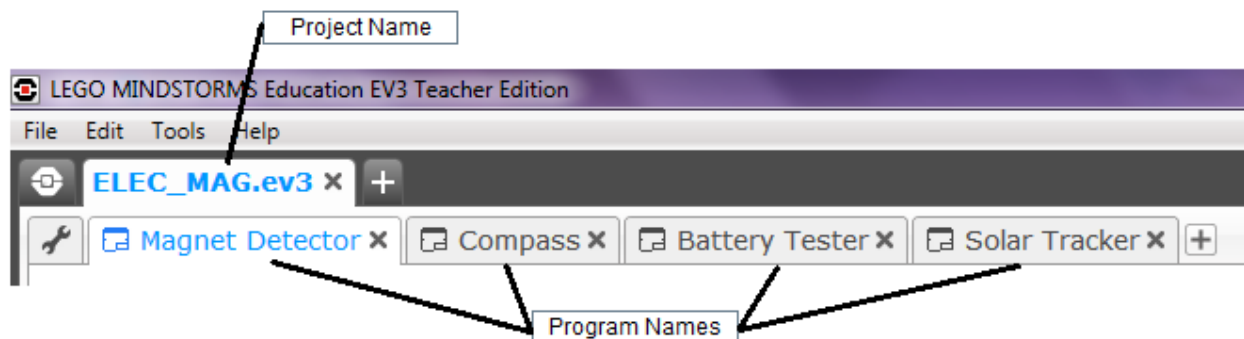
Pathway in the Lobby area for creating a new project

When you open the programming canvas, the Content Editor also opens by default. This is a very useful tool, but it tends to take up a lot of space in the window. To close it, simply click on the button in the upper-right corner. You can always reopen the Content Editor when you need it by clicking the Edit Mode button.



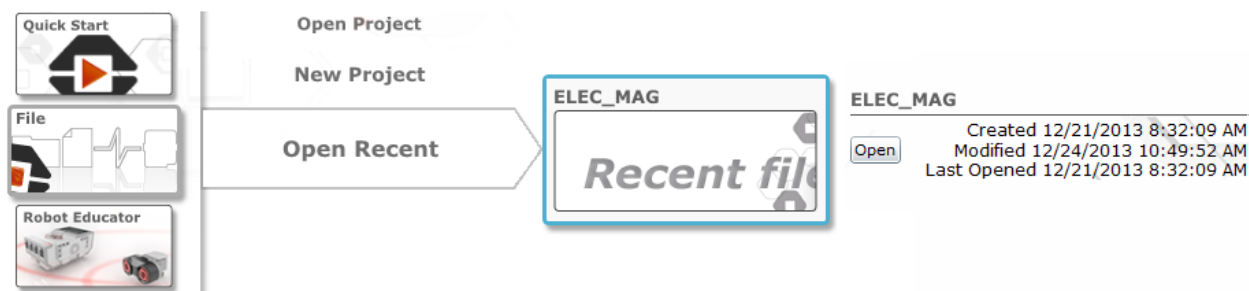
Content Editor navigation buttons

Before downloading your program to the EV3 Brick, you should give it a name and then save your entire project. You can change the program name simply by clicking on its tab and then typing in a new name. It is better to name your programs something recognizable, such as “Magnet Detector,” rather than an unintuitive name, such as “Joe’s 1st Try” since you will be writing multiple programs for this unit. The first time you save your project the software will ask you to enter a project name. If you are sharing a computer with other people, you may wish to add a unique descriptor onto your project name, such as “Joe’s Elec_Mag.” This name cannot be changed by clicking on its tab once it is set.



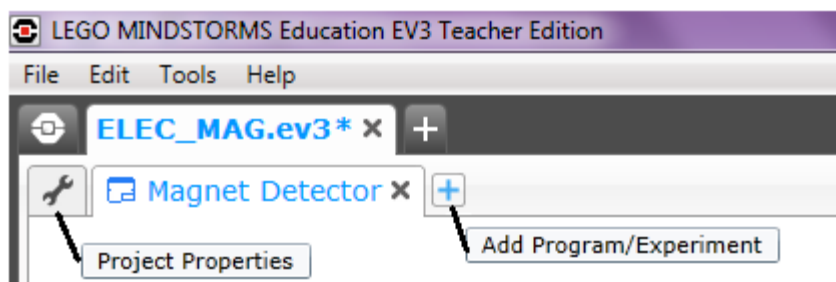
Project management bar

Once you have created a project with the EV3 software, you can reopen it from the Lobby either by clicking Open Project or Open Recent.



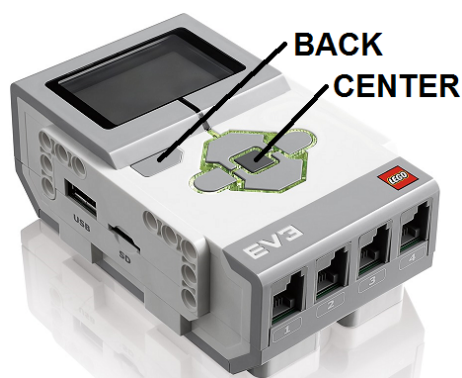
Pathway in the Lobby area for opening an existing project

From the Project page, you can click on the wrench in the upper left corner to go to the Project Properties page. From here you can add a title and a description of your project, as well as a picture of your robot or your team members. This information will be displayed the next time you are in the Lobby along with the creation, modification, and last opened dates. To add a new program, click on the plus sign next to your existing program. Be sure to click on the lower plus sign, because clicking on the upper plus sign will create a new project. Double-click on the new tab and enter a name for your program.



Project management tools

There are three options for downloading your program to the EV3 Brick: Wi-Fi, Bluetooth, or a USB cable connected to the computer. Whichever option you choose, it is better to click the Download button rather than the Download & Run button (you do not want your robot accidentally driving off the table.) Once the program is downloaded, place your robot in position and press the dark gray Center button to start the program. Press the Back button when you are ready to stop program execution.

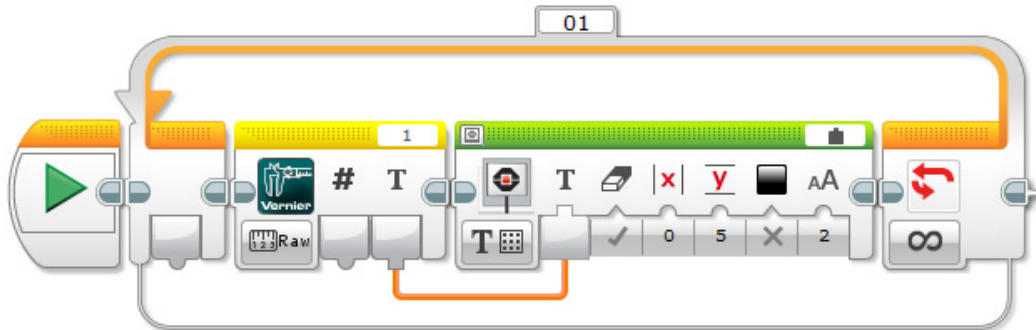


Program execution buttons

Vernier Sensor Measurements with the EV3 Brick

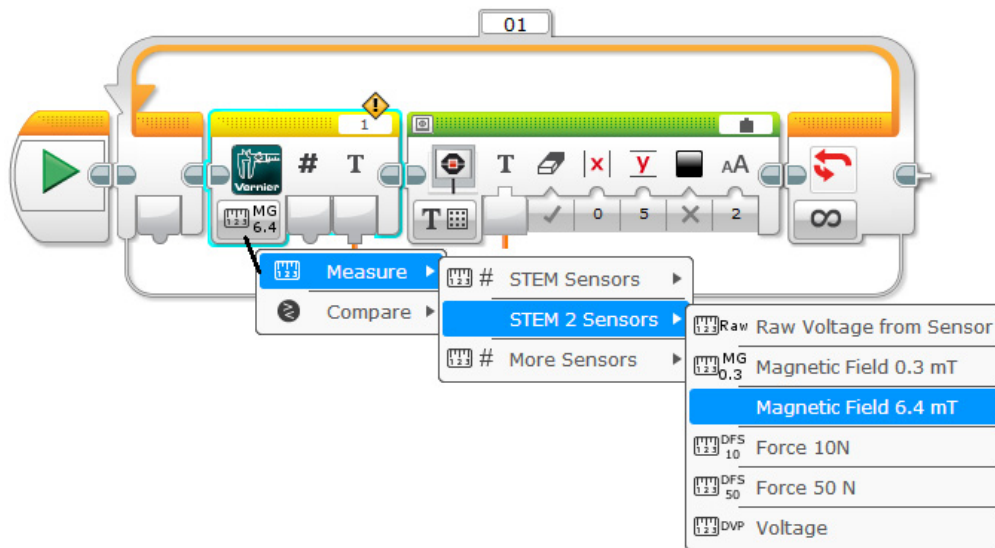
The simplest way to make measurements with any Vernier sensor is with the *Vernier Data Display* program. You can download *Vernier Data Display* from the Vernier website, or you can

write your own version of the program (shown below). Before using the program, you simply plug a sensor into the Vernier NXT Adapter, connect the adapter into Port 1 on the EV3 Brick, select a sensor from the drop-down menu in the Vernier Sensor block, and then download the program to your EV3. Measurements are continuously displayed with proper units until you press the Back button on the EV3.



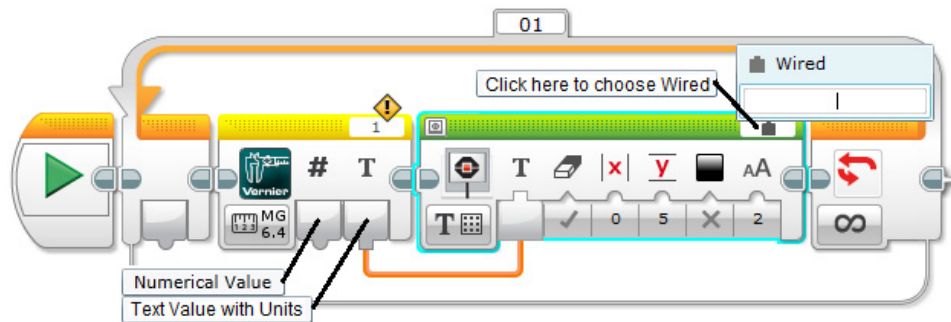
Vernier Data Display program for on-brick sensor measurements

You can choose from over 15 different sensors from the drop-down list within the Vernier Sensor block. Two of the drop-down lists correspond directly to the sensors used in Vernier's STEM curriculum books. Many Vernier sensors have multiple ranges or sensitivities, which are specified through the drop-down list. For example, the Magnetic Field Sensor has the capability of taking readings at a high or low-amplification, which corresponds to the 0.3 mT and 6.4 mT options, respectively.



Sensor selection from a drop-down list

Unlike the LEGO sensor blocks, the Vernier Sensor block allows you to directly display sensor values in numeric form or as a text value accompanied by its corresponding unit. (Note: You must choose the Wired option after selecting Text in the Display block in order to connect values from the Vernier Sensor block.)



Display options for Vernier Sensor Block

One thing to be aware of when using the Vernier Sensor block is the appearance of an exclamation point above the port number. The exclamation point is called a *resource conflict*. Normally a resource conflict means you are asking the EV3 to perform conflicting tasks, such as turning the robot's right wheel clockwise while turning the left wheel counterclockwise. When using the Vernier Sensor block, however, the exclamation point is simply a notification that you have plugged a non-LEGO sensor into one of the EV3 Brick's ports.

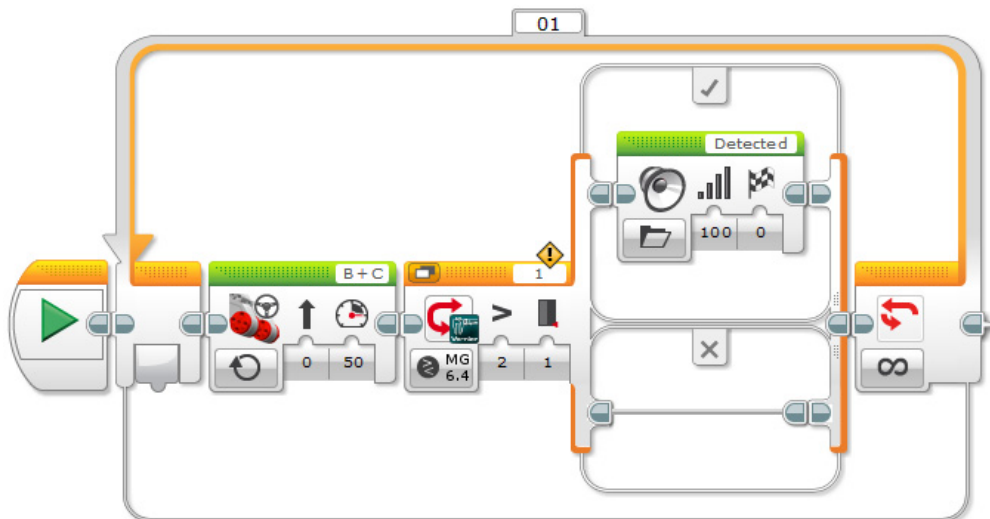
Materials Note

You need relatively strong, but compact magnets, for this activity. Small neodymium magnets in disc, block, or ring shapes work well. Programming will be somewhat easier if the magnet is always placed in a certain orientation (for example, with the South side up), since the sensor returns a positive value when the South side is facing up and a negative value when the magnet is flipped. You can use a black marker or small piece of tape to identify the two faces.

Use caution when working with neodymium magnets; they are incredibly strong. Two magnets snapping together at the wrong angle can pinch your fingers. To help prevent this from happening, glue each magnet to the underside of a LEGO brick. This has the added benefit of making the tiny disk magnets easier to find when they are scattered on the floor.

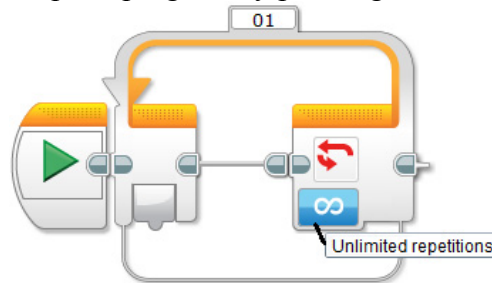
Programming

In this activity, your task is to design a program to make the robot drive forward and play a sound every time it passes a magnet. A sample program, called *Magnet Detector*, is shown below.



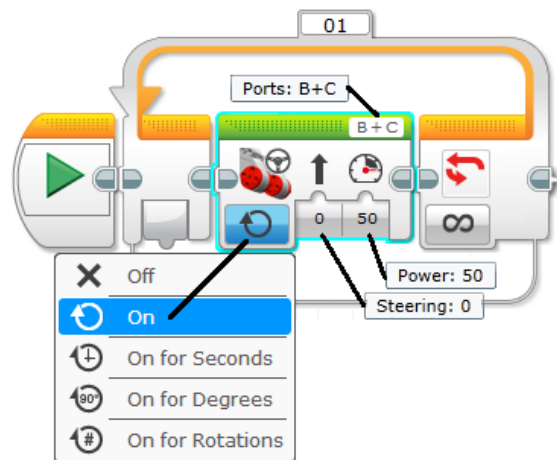
Sample program for detecting a magnet

Since you are trying to detect more than one magnet, the first block you should lay down onto the programming canvas is a Loop block (found in the Flow Control palette). A *Loop* allows the robot to repeat a set of actions. Repetitions can be specified by a number of counts or a length of time, but the default mode assumes an Unlimited number of repetitions. This allows your robot to continue running until you stop the program by pressing the Back button on the EV3 Brick.



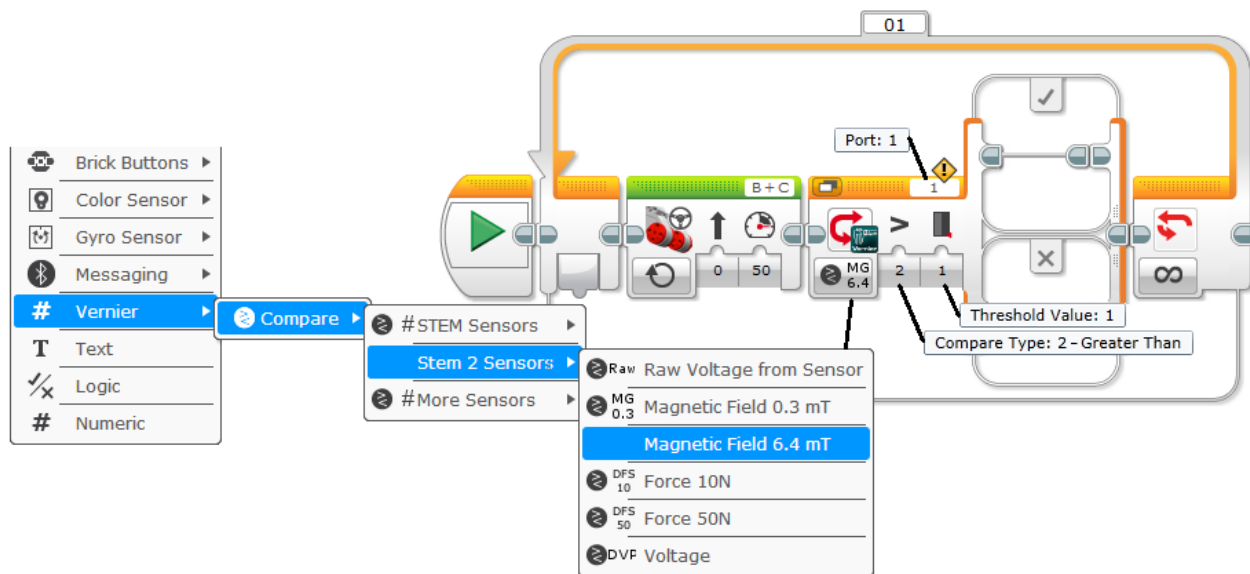
Configuration settings for Loop block

Your robot's first action is to drive forward. Place a Move Steering block (found in the Action palette) inside the Loop. Since the robot does not know where the first magnet is located, adjust the mode to On so that the robot will drive forward continuously. Make sure the Ports are set to B and C for the two drive motors. The Steering should be set to 0 to make the robot drive in a straight line with no turns. The Power setting equates to the speed of the robot with values ranging from 0 to 100. Adjust the Power setting to correspond to your practice field and your robot's battery charge. Setting the Power level too high could cause the robot to drive right past the magnet without giving the Magnetic Field Sensor time to detect it.



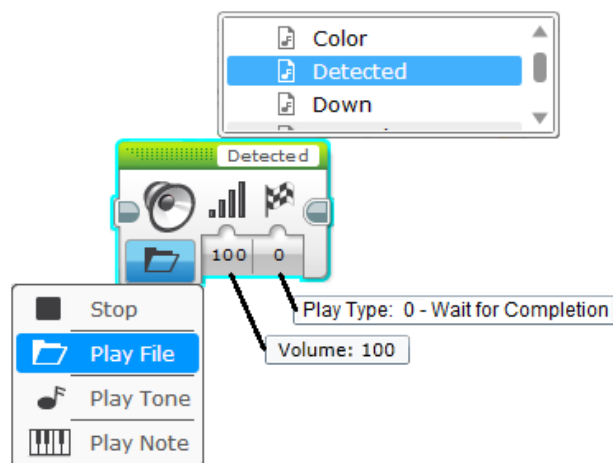
Configuration settings for Move Steering block

Next, you want to determine whether the robot is near a magnet. Place a Switch block (found in the Flow Control palette) inside the Loop to the right of the Move Steering block. A *Switch block* allows you to ask a yes/no question and run two different actions depending on the answer to the question. In this program, you will be using a sensor to determine whether the robot is near a magnet. Set the mode on the Switch block to Vernier » Compare » STEM 2 Sensors » Magnetic Field 6.4 mT. Adjust the Comparison type to 2: Greater Than. Define a threshold value from your engineering notebook – something a little less than the maximum magnetic strength of your neodymium disc magnet. Be sure the Port Number on the Switch block matches the port into which you plugged the Magnetic Field Sensor.



Configuration settings for Switch block

The final step is to place one or more Sound blocks (found in the Action palette) within the Switch block. The EV3 software contains over 50 pre-recorded sound files for you to choose from. You can also play a tone, play a musical note, or record your own sounds. The True and False cases on the Switch block are designated by a checkmark ✓ and an X, respectively. In the sample program, a sound file was placed within the True case to allow the robot to say “Detected” when it passed a magnet. The Volume was adjusted to the highest setting (100) and the Play Type was left at the default value of 0. No action is necessary in the False case; the program will simply loop back around and repeat.



Configuration settings for Sound block

This is obviously an extremely simple program that meets the basic requirements. However, encourage your students to go beyond the minimum expectations and design a more creative solution. For example, you can place multiple Sound blocks in the Switch statement so the robot can say a complete sentence. The robot can play a song or twirl in a circle. The robot can deposit a LEGO minifigure to mark the location of the magnet. The number of solutions is endless and only limited by the imagination of your students.

Batteries

Task

Build a robot that can distinguish good batteries from “dead” batteries.

Objectives

- Learn how a battery works
- Learn the proper terminology for electrical components
- Learn how to use a voltage probe
- Measure the electric potential of different battery types (AAA, AA, C, D)
- Measure the electric potential of stacked batteries (1, 2, 3, 4)
- Distinguish between fresh and dead batteries
- Build a gearing mechanism for a robotic gripper

Vocabulary

- battery
- current
- electric potential
- ground
- negative lead
- positive lead
- voltage

Materials (for each team)

- LEGO robotics kit
- Differential Voltage Probe (Vernier DVP-BTA)
- NXT Sensor Adapter (Vernier BTA-NXT)
- an assortment of fresh batteries: 1 AAA, 4 AA, 1 C, 1 D
- an assortment of AA batteries at various voltages (including some “dead” batteries)
- ruler
- engineering notebook
- pencil

Preparation

1. Optional: Build a robotic gripper and battery support according to the *Battery Tester* and *Battery Tester Base* building guides found in *Appendix C* to use as a demonstration example.

Order of Activities

1. Explain the concept of electric potential and how it relates to a common battery. Let students examine their batteries and make predictions as to what the various sizes mean. (15–35 min)

2. Demonstrate how a Vernier Differential Voltage Probe works. Have students modify the *Vernier Data Display* program so they can use the voltage probe to measure the electric potential of AA, AAA, C, and D batteries. (10–20 min)
3. Discuss with students whether their measurements met with or differed from their predictions. (10–15 min)
4. Have students predict and then measure the voltage of several AA batteries stacked together. Ask them to derive the mathematical relationship between the number of batteries and the total voltage. Have them predict what the voltage would be if 10 batteries were stacked together. (10–20 min)
5. Explain to students what constitutes a “dead” battery. Have them measure various AA batteries to determine if they are good or dead. (10–25 min)
6. Have students design and build a robotic gripper and battery support similar to the models in the *Battery Tester* and *Battery Tester Base* building guides in *Appendix C*. Let teams work at their own pace giving verbal guidance only when asked. (35–60 min)

Additional Model Instructions: The motorized mechanism for the robotic gripper is similar to the gripper on the end of the Robot Arm H25 model. If your students need a little additional help with construction, have them look over the Model Instructions found in the Model Core Set section of the software Lobby.

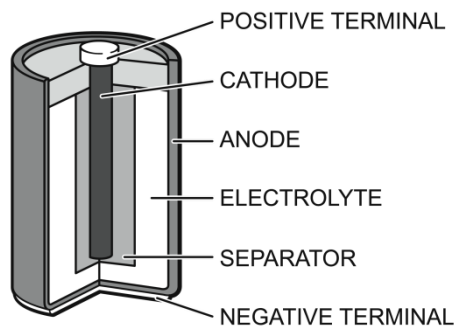
7. Have students write a program to turn their robots into automatic battery testers. When a battery is placed in front of the robot and the Center button is pressed, the gripper arms should close around the battery so that the two leads of the voltage probe are touching the terminals of the battery. The EV3 should give an audio indicator as to whether the battery is fresh or dead. (30–55 min)

Robot Educator Tutorial: This activity requires that the robot close and retract a set of voltage probes around a battery. If your students need a little additional programming instruction, have them work through Tutorial #5, *Move Object*, in the Basics section of the Robot Educator. This tutorial teaches students how to control motorized attachments connected to the Medium Motor.

8. **Challenge for Early Finishers:** Add an ultrasonic sensor to the robot to automatically detect when a battery is present.

Background

A battery is a device that changes chemical energy into electrical energy. It is made up of six main parts: an anode, a cathode, an electrolyte, a separator, and two terminals labeled positive (+) and negative (–). In AA, AAA, C, and D cell batteries the *terminals* are the metal elements at the ends of the battery. The *cathode* is connected to the positive terminal and the *anode* is connected to the negative terminal. An oxidation reaction in the anode produces electrons and a reduction reaction in the cathode absorbs them. A *separator* prevents the anode and cathode from touching while a paste, called an *electrolyte*, allows the electric charge to flow between them.

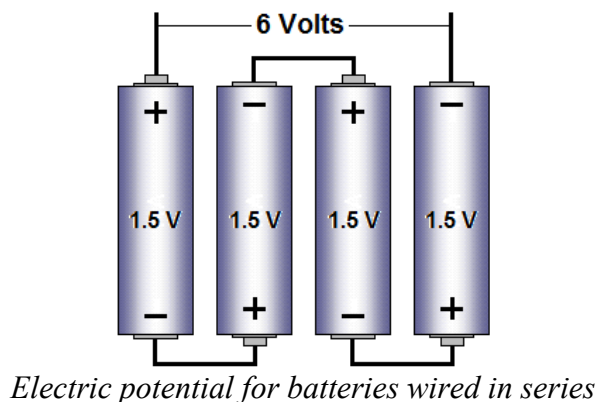


Composition of a battery

If you connect a wire between the two terminals, electrons will flow from the negative to the positive terminal. When electrons flow, the result is electricity. A battery will continue to produce electricity until the anode or the cathode runs out of the material needed for a reaction to occur. A battery will not produce electricity unless a *load*, such as a light bulb, a motor, or the previously-mentioned wire, is connected to the two terminals. That is why a battery can sit on a shelf for a year and still have plenty of power.

The storage capacity of a battery, rated in milliamp-hours (mAh), is roughly proportional to its size. *Storage capacity* is the total electrical current a battery can deliver in one hour. *Current* is the rate at which electrons pass through a circuit and is similar to the rate at which water flows through a hose. Most devices, however, do not require the entire load current at once. For example, a typical household battery rated at 500 mAh would be able to supply 500 mA of current to a motor for 1 hour or 50 mA to a fan for 10 hours or 5 mA to a light for 100 hours – any proportion as long as the product of the two numbers equals 500. Generally, larger batteries have higher milliamp-hour ratings due to their larger capacities.

On the other hand, the electric potential of a battery (often referred to as *voltage*) has no relation to its physical size but rather depends on the materials used in its construction. For example, even though AA, AAA, C, and D cell batteries are different sizes, they have identical voltages when fresh. *Electric potential* determines how strongly electrons are pushed through a circuit much like pressure determines how strongly water is pushed through a hose. Alkaline batteries are normally rated at 1.5 volts, while rechargeable Ni-MH batteries have a slightly lower voltage at 1.4 volts. You don't normally use just one battery to power a device however. Typically batteries are grouped together in series by connecting the positive terminal of one battery to the negative terminal of another battery. Referring to the diagram below, four batteries rated at 1.5 volts each would actually deliver 6 volts to a device if connected in series.



A common misconception is that the voltage in a discharged battery (often referred to as a “dead” battery) is zero. In reality the voltage usually lies somewhere within the range of 0.8 to 1.0 volts, but the remaining voltage is not strong enough to push electrons through the circuit.

Fun Fact

The Curiosity rover uses a nuclear battery to provide power. Unlike previous rovers that used solar panels to power their systems, the nuclear battery can provide constant power during the night and during the Martian winter when the sun's light is not available. The Multi-Mission Radioisotope Thermoelectric Generator (MMRTG for short) is an energy source that relies on the heat generated by decaying plutonium dioxide to run Curiosity. It is designed to supply

continuous power for 14 years. The nuclear generator delivers both electric power and heat, since Curiosity's testing and communications equipment requires a certain temperature to operate effectively on Mars where temperatures often dip far below freezing. Nuclear power has been used in 26 previous space missions over the past 50 years, but this is the first time nuclear energy has been used to power a rover.

Sensor Notes

You can use the Vernier Differential Voltage Probe to measure the electric potential of common household batteries in the range of ± 6 volts. The probe features two clips (red and black) that can be connected to the positive (red) and negative (black) terminals of a battery. If you connect the clips in reverse order, your measurements will be displayed as negative values.

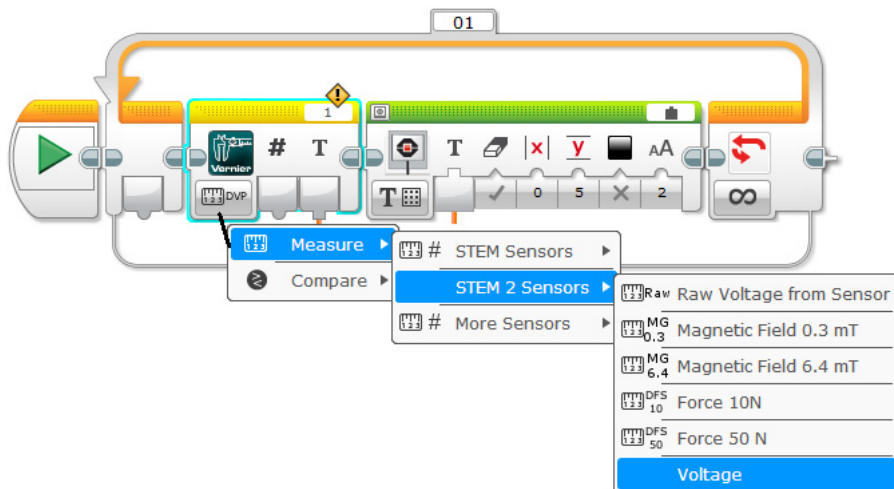


Vernier Differential Voltage Probe

You can connect the Differential Voltage Probe to the EV3 Brick the same way you connected the Magnetic Field Sensor. Plug the voltage probe into the BTA connector on the Vernier NXT Sensor Adapter and then connect the adapter to any numbered port on the EV3 Brick.

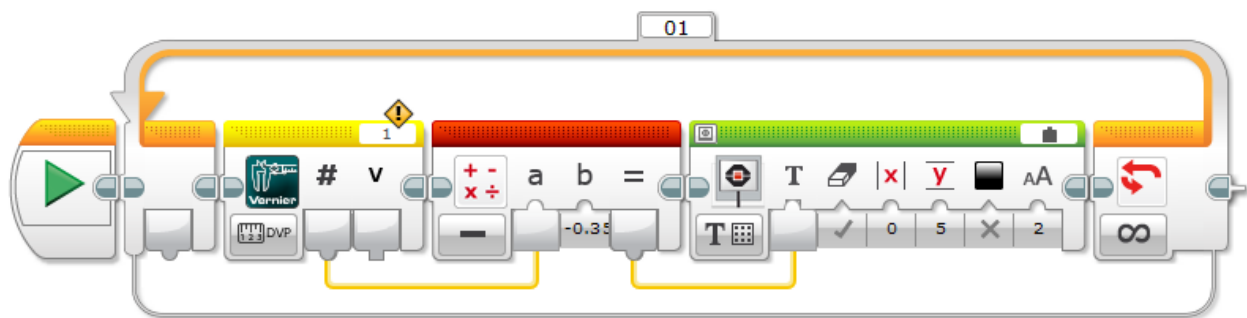
Vernier Sensor Measurements with the EV3 Brick

You can measure the electric potential of batteries with the Differential Voltage Probe and the *Vernier Data Display* program. In the Vernier Sensor Block, select Voltage from the STEM 2 drop-down list. (Note: Do not choose Raw Voltage as this is a generic uncalibrated value intended for use by those who build their own sensors.) Make sure the sensor is connected to Port 1 on the EV3 Brick.



Vernier Data Display program for measuring voltage

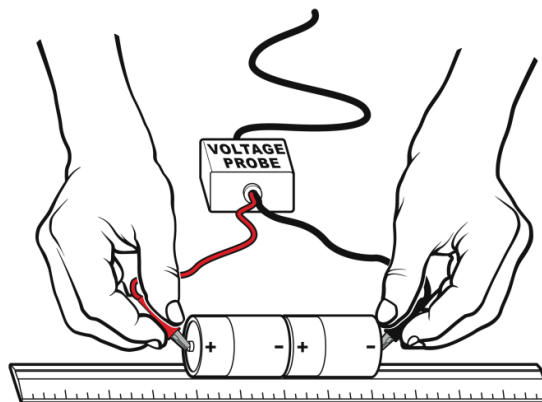
One limitation when using the EV3 Vernier Sensor block is that it does not have a Zero function. In many situations this is not significant, because you are more concerned with the relative difference between measurements rather than the actual value. When using the Differential Voltage Probe to measure AA batteries, however, it is important to know the actual value since a fresh battery should read 1.5 volts. You can easily overcome this limitation by subtracting an *offset* value from the sensor reading. Connect the red and black clips on the voltage probe together and take a reading with the *Vernier Data Display* program. In real life, the measurement should be zero. Any value other than zero will be your offset value. Before using the *Vernier Data Display* program to test your AA batteries, modify it to subtract the offset value from your sensor reading as shown below.



Modified Vernier Data Display program to zero a probe

Materials Note

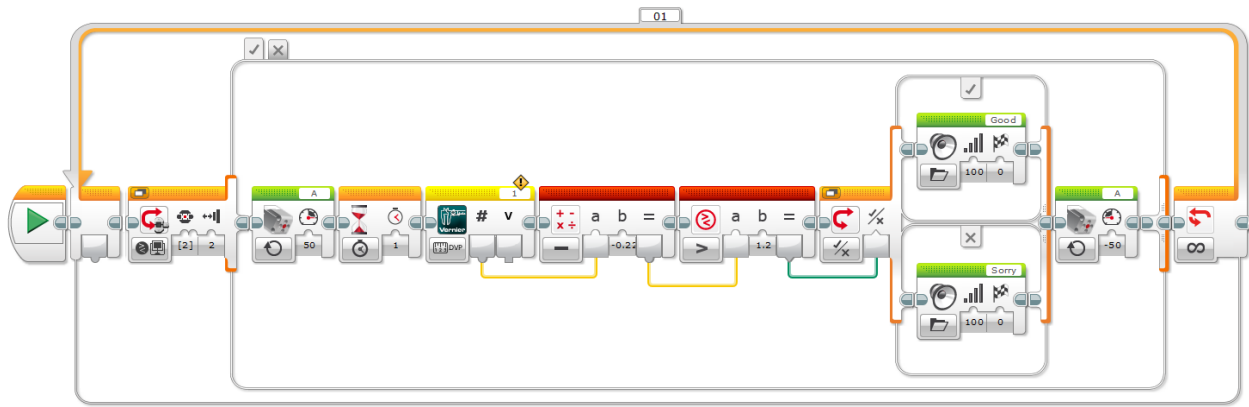
A wooden or plastic ruler with a groove down the middle provides an excellent surface for holding batteries in place while making measurements.



Testing batteries with a voltage probe

Programming

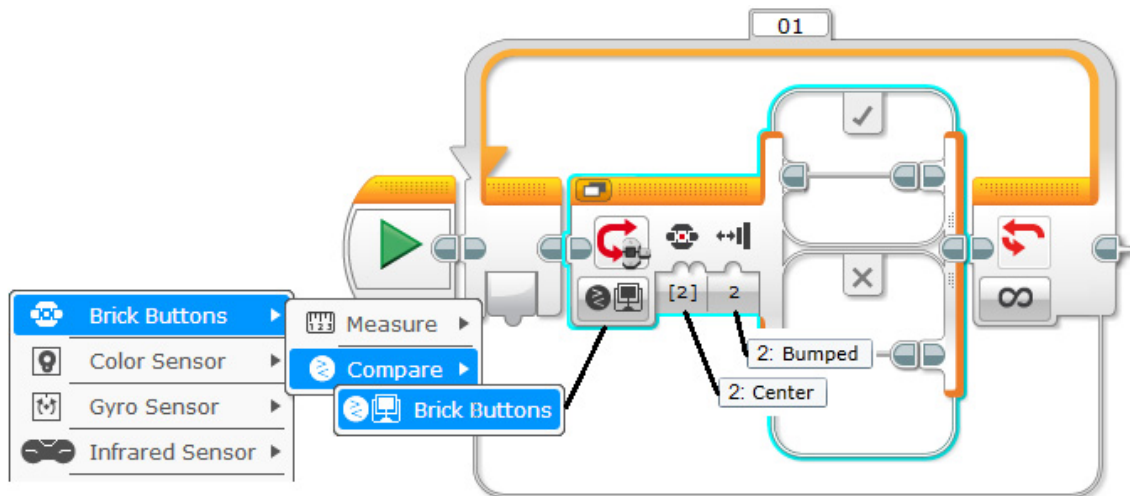
In this activity your objective is to design a program to determine if an AA battery is good or dead. A sample program, called *Battery Tester*, is shown below.



Sample program for testing a battery

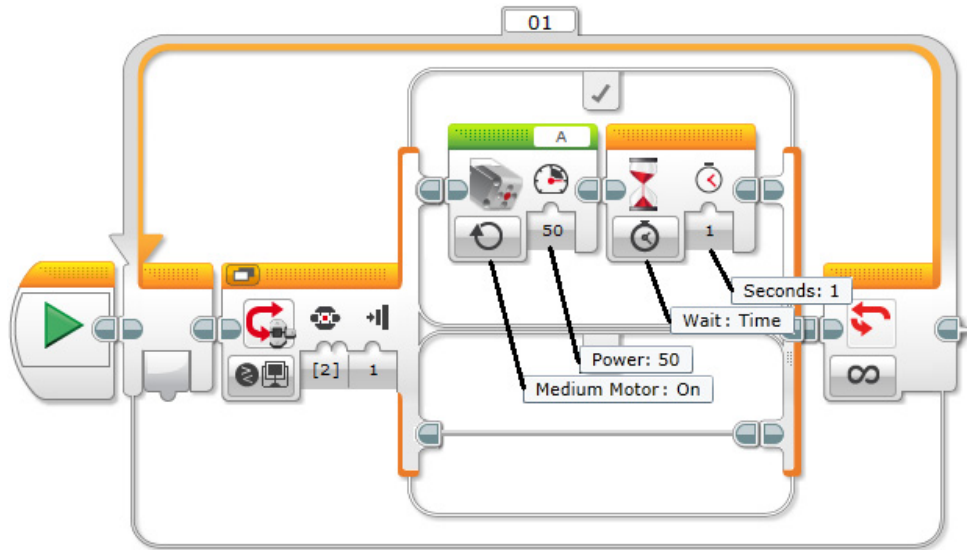
Since you are trying to test an unknown number of batteries, the first block you should lay down onto the programming canvas is a Loop block. Keep the default mode of Unlimited repetitions.

Your task is to make the robot touch the leads of the voltage probe to the battery terminals, but first you need to let the robot know that a battery has been placed in front of it. There are many ways to do this, such as using one of the sensors in the EV3 kit to detect the presence of the battery. The sample program assumes the user will simply press the EV3 Brick's Center button after placing a battery in the holder to signal the robot's gripper to close. To program the Center button, place a Switch block inside the Loop and set the mode to Brick Buttons » Compare » Brick Buttons. Adjust the Button ID to 2: Center, and set the State to 2: Bumped. Any button state will work; "bumped" simply means the Center button has been pressed and released.



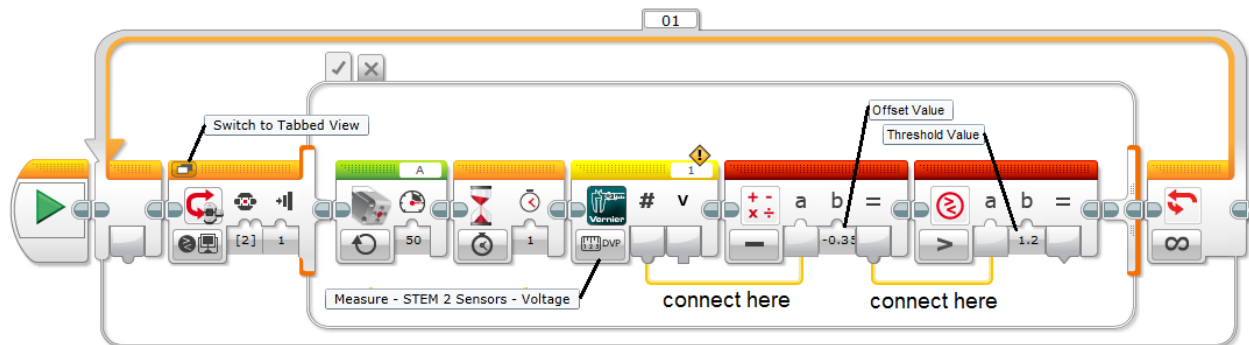
Configuration settings for first Switch block

If the Center button has been bumped, you want the gripper arms to close around the battery (the True case on the Switch block). If the Center button has not been bumped, you do not want any action to occur (the False case). Since you attached the gripper arms of your battery tester to the smaller of the motors in your kit, you would control it by placing a Medium Motor block (found in the Action palette) inside the True case of the Switch block. Set the mode to On to ensure that the gripper arms keep the voltage clips tight against the battery terminals while measurements are being taken. Set the Power to 50 and make sure the motor is connected to the A port on the EV3. Place a Wait block (found in the Flow Control palette) after the Medium Motor block to give the voltage probe time to get a good reading (1 second should be sufficient).



Configuration settings for first Medium Motor block

Next, you will need to take a sensor reading from the voltage probe, subtract an offset value, and compare it to a threshold value for distinguishing a good battery from a dead battery. (As described previously, subtracting an offset value is the way to zero the sensor.) Place a Vernier Sensor block (found in the Sensor palette) to the right of the Wait block and select Measure » STEM 2 Sensors » Voltage from the drop-down list. Be sure the Port Number on the Vernier Sensor block matches the port into which you plugged the Differential Voltage Probe. (Notice in the diagram below that the Switch block has been converted to Tabbed View to make this program easier to read. Only the True case is shown, since there are no actions taken in the False case.)

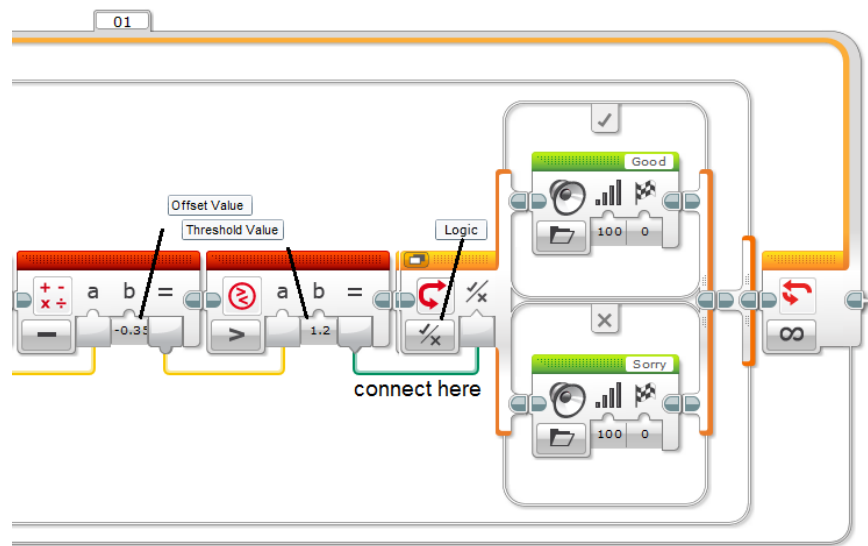


Configuration settings for making voltage comparisons

Place a Math block (found in the Data Operations palette) to the right of the Vernier Sensor block. Set the mode to Subtract and wire the Numerical Value from the Vernier Sensor block to the “a” box on the Math block. Enter your offset value into the “b” box. Place a Compare block (found in the Data Operations palette) to the right of the Math block. Set the mode to Greater Than and wire the Result from the Math block to the “a” box on the Compare block. Enter the threshold value from your engineering notebook into the “b” box.

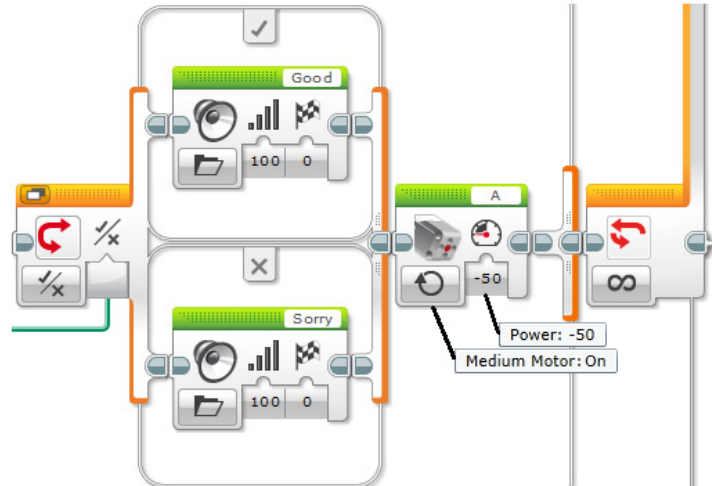
In the next step, you want to play a sound file to indicate the status of the battery. Place a second Switch block to the right of the Compare block and set the mode to Logic. Connect the Result from the Compare block to the Logic box on the Switch block. Place Sound blocks in both the

True and False cases. The True case will represent a good battery, and the False case will represent a dead battery, so choose appropriate sound files. The sample program used “Good” for the True case and “Sorry” for the False case.



Configuration settings for second Switch block

The final step in the program is to retract the voltage probe away from the battery. Place a second Medium Motor block to the right of the innermost Switch block. Set the mode to On and set the Power to -50 so that the probe will retract the gripper arms.



Configuration settings for second Medium Motor block

Compasses

Task

Build a robot that can point toward the North Pole.

Objectives

- Learn how a compass works
- Graph the magnetic field around a bar magnet
- Graph the ambient magnetic field around the classroom due to the Earth's magnetic poles
- Build and program a robot to point toward the North Pole

Vocabulary

- ambient
- amplification
- angle
- cardinal direction
- circumference
- compass
- data
- intercardinal direction
- parallel processing
- protractor
- rotation
- sine curve

Materials (for each team)

- LEGO robotics kit
- Magnetic Field Sensor (Vernier MG-BTA)
- NXT Sensor Adapter (Vernier BTA-NXT)
- compass
- protractor
- ruler
- paperclip
- 2 bar magnets
- iron filings
- clear re-sealable sandwich bag
- engineering notebook
- pencil

Preparation

1. Place a small quantity of iron filings into a clear plastic sandwich bag (approximately 1 tablespoon). You can buy iron filings from a science supply store or make your own from an iron nail. Hold the nail with a pair of pliers and scrape across the tip with a metal file.

2. The intensity of the Earth's magnetic field is very dependent upon your location. Some buildings have enough metal in their structures to effectively block out the Earth's magnetic field. You should do some initial testing to determine that a change is actually occurring in the sensor reading when the white dot on the Magnetic Field Sensor is pointed due north. Be sure to slip the switch on the sensor to the high amplification setting (0.3 mT) before taking your readings.
3. Optional: Modify the holder for the Magnetic Field Sensor so that it can be mounted onto the front of the robot. Instructions for one possible solution are given in the *Front Sensor Holder* building guide found in *Appendix C*.

Order of Activities

1. Explain how a compass works. Let students investigate the behavior of their compasses as they point them in different directions. Ask students to compare the cardinal and intercardinal directions on the compass to the angles on a protractor. Have them record their observations in their engineering notebooks. (10–20 min)
Math Extension: Demonstrate how the LEGO gyro sensor measures angles like a protractor.
2. Have students observe the behavior of the compass needle when it is brought near a bar magnet. Discuss the results of their observations. (10–20 min)
3. Demonstrate how to view the magnetic field around a bar magnet by laying a sandwich bag with iron filings over the magnet. Gently shake the bag to distribute the iron filings. Have students sketch the pattern made by the iron filings in their engineering notebooks for three different orientations. (10–20 min)
 - a. single bar magnet
 - b. the north poles of 2 bar magnets placed an inch apart
 - c. one north pole and one south pole of two bar magnets placed an inch apart
4. Have students investigate the strength of a magnetic field using the following procedure. Lay a ruler on the table. Place a paper clip on the ruler's zero mark. Line up a magnet at the other end of the ruler and very slowly slide the magnet toward the paper clip. When the paper clip attaches to the magnet, stop and record the distance. By measuring how far the magnet is from the paper clip when it becomes attracted to the magnet, you are finding the length of the magnetic field. Stronger magnets can attract objects from a farther distance than weaker magnets can. (15–30 min)
5. Have students modify the *Vernier Data Display* program so they can use the Magnetic Field Sensor to map the magnetic field strength along a single bar magnet. Be sure the select the low amplification setting (6.4 mT) in the Vernier Sensor Block before downloading the program to the EV3. (10–15 min)
6. Have students measure and record the magnetic field strength along a single bar magnet. Lay the sensor flat on the table with the white dot pointed toward the north pole of the bar magnet. Slowly rotate the magnet so that the sensor is pointing toward the middle, then the south pole, then the middle, and back to the north pole. (5–10 min)
7. Have students graph the magnetic field strength of a bar magnet in their engineering notebooks and label the points on the graph where the sensor was pointed toward the north pole, south pole, and middle of the magnet. Discuss how a sine curve differs from a line graph. (5–10 min)
8. Have students measure and record the ambient magnetic field strength around the classroom due to the Earth's magnetic poles. Modify the *Vernier Data Display* program to use the Magnetic Field Sensor at the high amplification setting (0.3 mT). Be sure to flip the switch on the sensor to the 0.3 mT setting. Use a compass to orient the zero mark on the protractor so that it is pointing towards the North Pole. (10–15 min)

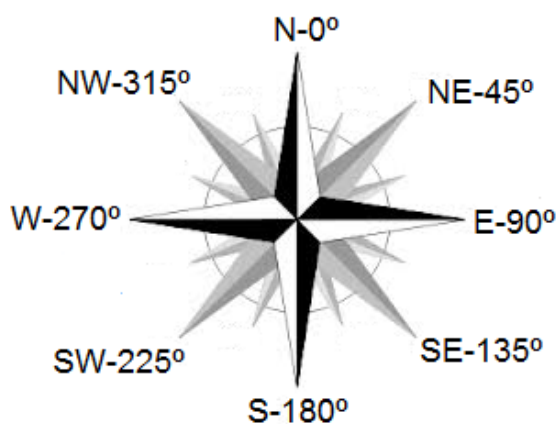
9. Have students graph the ambient magnetic field strength around the classroom in their engineering notebooks. Label all peaks and valleys. (10–20 min)
10. Have students alter their holder for the Magnetic Field Sensor so that it can be mounted onto the front of the robot. (15–25 min)
11. Have students write a program to make the robot turn in a complete circle and then point toward the North Pole. Students should verify the orientation of their robots with a handheld compass. (20–45 min)

Robot Educator Tutorial: This activity requires that the robot spin around while searching for the location of the highest magnetic field reading. If your students need a little additional programming instruction, have them work through Tutorial #13, *Variables*, in the Beyond Basics section of the Robot Educator. This tutorial teaches students how to use variables to store information that the robot can later use to determine its driving pattern.

12. **Challenge for Early Finishers:** Add a gyro sensor to make the robot point in one of the four cardinal directions – North, South, East, or West.

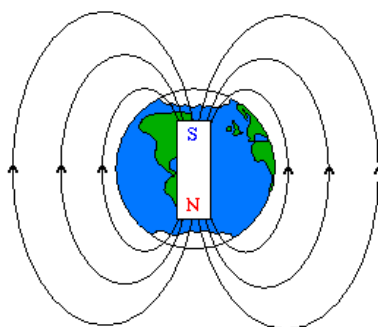
Background

A compass is a navigational instrument used to determine geographic direction. It contains a lightweight magnetized needle that always points toward the North Pole of the Earth. The circle of a compass face is divided into 360 degrees with four *cardinal* directions – North, South, East, and West. The directions halfway between the cardinal directions (Northeast, Southeast, Southwest, and Northwest) are called *intercardinal* directions. *Relative* directions like “left” and “right” can vary depending on your orientation, but cardinal and intercardinal directions are always constant.



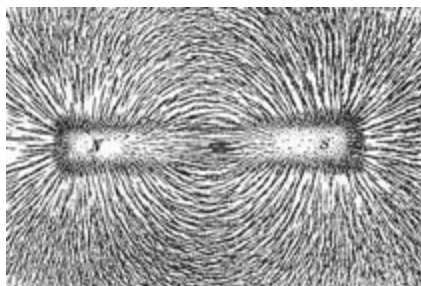
Compass face showing cardinal and intercardinal directions

The needle of a compass will always align itself with the Earth’s magnetic field unless the needle is around a strong magnet. The Earth’s magnetic field is caused by the rotation of the Earth’s liquid core, and ranges from 0.03 to 0.06 milliTesla (mT). You can think of the Earth as having a giant bar magnet buried inside. In order for the north end of a compass to point toward the North Pole of the Earth, the bar magnet must be buried with its south end at the North Pole.



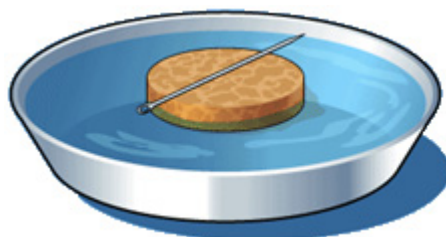
Earth's magnetic field lines

The magnetic field lines around a bar magnet form a similar pattern to the Earth's magnetic field lines. They extend out from the north pole, and then curve back into the south pole. You can see these field lines by placing a clear plastic sandwich bag of iron filings over the top of a bar magnet.



Magnetic field around a bar magnet using iron filings

You can make your own compass by floating a needle in a dish of water. First, you must magnetize the needle by stroking it with another magnet about 10–20 times. You should stroke the needle in one direction only rather than rubbing it back and forth. Next, place the magnetized needle on top of something lightweight that floats in a shallow dish of water, such as a piece of cork, the bottom of a Styrofoam[®] cup, or the cap from a milk jug. When you remove your hand, the magnetized needle will gradually turn until it is pointing toward the North Pole.



Homemade compass using a needle and bowl of water

Fun Fact

Mars does not have North and South Poles like Earth, because it does not have an inner dynamo capable of producing a magnetic field. Its core appears to be made of solid iron, rather than liquid iron. Consequently the Curiosity rover cannot use a traditional compass for navigation. Instead, the rover uses two pairs of black and white navigation cameras (*navcams*) and four pairs of hazardous avoidance cameras (*hazcams*) to maneuver around the rocky Martian surface. Navcams are mounted on the mast and have a 45° viewing angle. Hazcams are mounted on each corner of the rover and have a 120° viewing angle. The cameras are mounted in pairs, because when simultaneous images are taken of Mars, they can produce a 3D map of the surroundings.

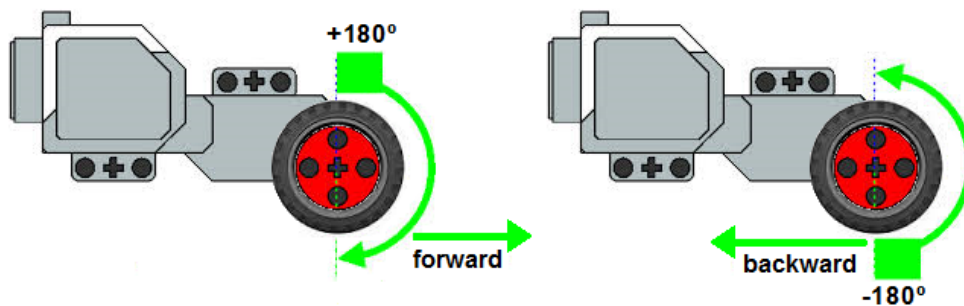
Pictures are sent to one of two onboard computers, which allow the rover to plan its next move to avoid crashing into rocks or other obstacles.

Sensor Notes

In this activity, you will use a Magnetic Field Sensor for two activities: to map the magnetic field along a bar magnet and to determine the direction of the Earth's North Pole. When mapping the magnetic field along the bar magnet, be sure to set the switch on the sensor to the low amplification setting (6.4 mT). When programming the EV3 to act as a compass, you should flip the switch to the high amplification setting (0.3 mT). The Magnetic Field Sensor will return the highest reading when the white dot is pointed toward the North Pole. (Remember, the North Pole of the Earth is like the south pole of a bar magnet.)

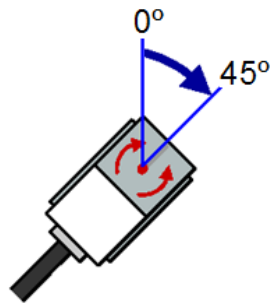
When using the robot as a magnet detector, it is better to locate the sensor to the side of the robot so that the robot does not drive over the magnets. The robot's motors have internal magnets that will cause the motors to attract other magnets if they get too close. However, when using the robot as a compass, you should locate the Magnetic Field Sensor on the front of the robot. This ensures that the robot is oriented toward the North Pole when it turns back to the highest sensor reading. When making your attachments, be sure the sensor is pointed away from the robot's motors as the magnets inside the motors can interfere with the sensor readings.

You may also wish to use LEGO's rotation sensor and/or gyro sensor when building your robotic compass. The rotation sensor measures the turns made by the motor shaft. Unlike other sensors that must be connected to one of the input ports on the EV3 Brick, the rotation sensors are built into the motors. Each motor contains its own sensor. Motor rotations can be measured in degrees or full rotations (1 rotation is equal to 360 degrees). A common misconception is that the rotation sensor controls the turns made by the robot; this is not true. The rotation sensor is used to control the linear distance traveled by the robot. Degrees and rotations are used to indicate the number of turns made by the motor shaft, not the direction the robot turns. For example, if you tell the motor to turn 360 degrees, the wheel attached to the motor shaft will drive forward a distance equal to its circumference (the length around the perimeter of the wheel). This distance will vary depending on the size of your wheels.



LEGO's rotation sensor is built into the motor

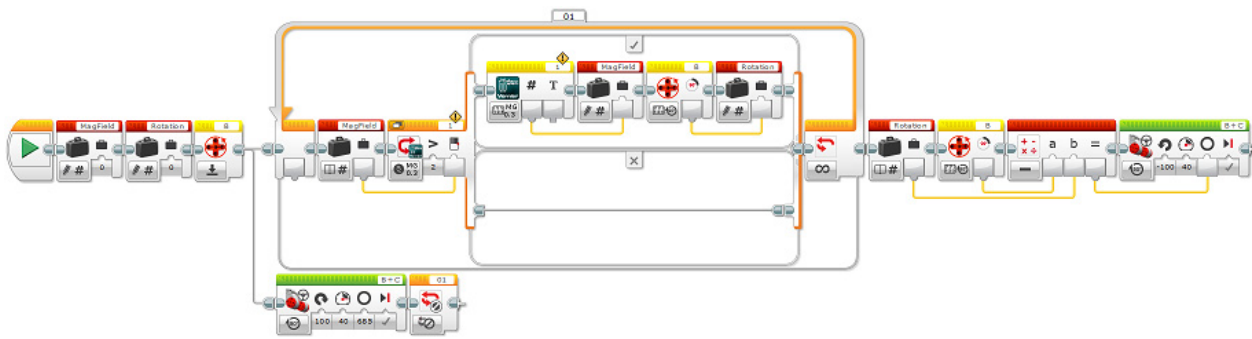
LEGO's gyro sensor measures the robot's rotational motion. Unlike the rotation sensor, the gyro sensor measures the angle that the robot has turned, not how far the wheels have rotated. When you use the gyro sensor, you should always reset it back to zero so that its angles are measured relative to its starting position. When using the gyro sensor to make 90° turns, the sensor has an accuracy of $\pm 3^\circ$.



LEGO's gyro sensor used for making angular measurements

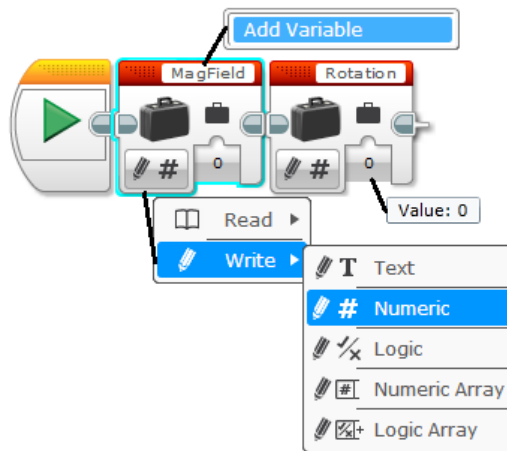
Programming

You can use the Vernier Magnetic Field Sensor and LEGO's rotation sensor to turn your robot into a compass. Mount the Magnetic Field Sensor on to the front of the robot and then write a program to make the robot rotate completely around taking sensor readings as it turns. The highest magnetic field reading will correspond to the North Pole of the Earth. The corresponding reading from the rotation sensor will indicate how many rotations were made by the drive wheel to get to that point. A sample program is shown below.



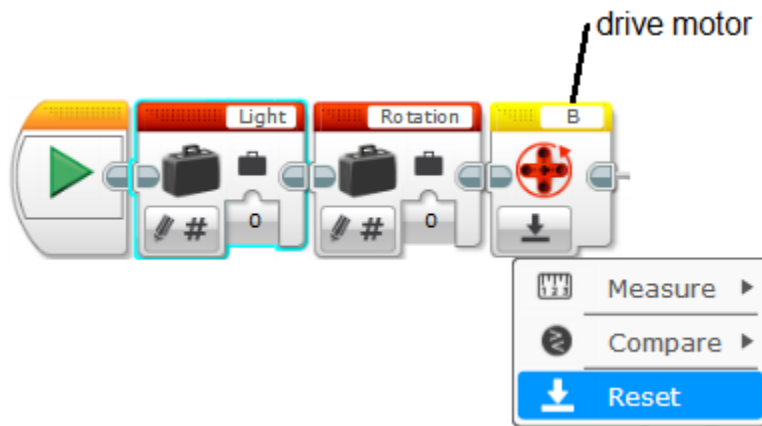
Sample program for a robotic compass

You can keep track of readings from both sensors with Variable blocks. A *variable* is a container for storing information. Your first task when using variables is to initialize them. You will need to place two Variable blocks (found in the Data Operations palette) onto the programming canvas – one to store the value of the Magnetic Field Sensor and the second to store the value of the rotation sensor. Enter names for both variables into the text box. To add a new name, click on the text box and select Add Variable. Always try to pick variable names that best represent the information being stored. Set the mode on both variables to Write » Numeric and enter an initial value of 0.



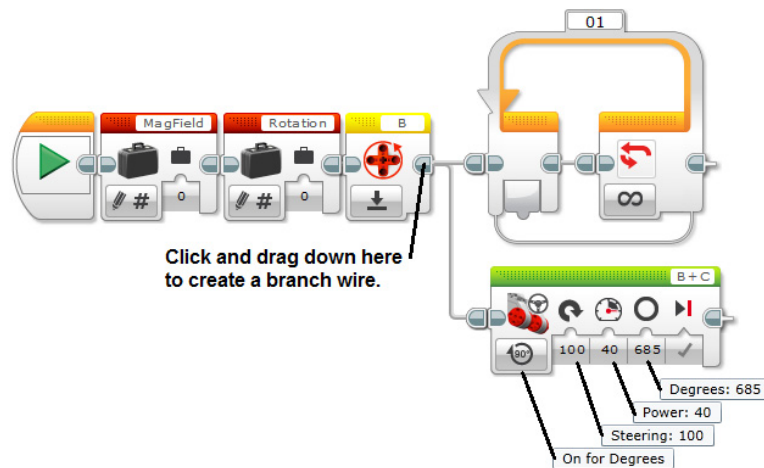
Configuration settings for initializing variables

When you use the rotation sensor, you must reset its counter to zero. To do this, lay down a Motor Rotation block (found in the Sensor palette) and set its mode to Reset. The drive motor you select should correspond to the direction of your robot's rotation – Port B for clockwise or Port C for counterclockwise (the sample program used Port B).



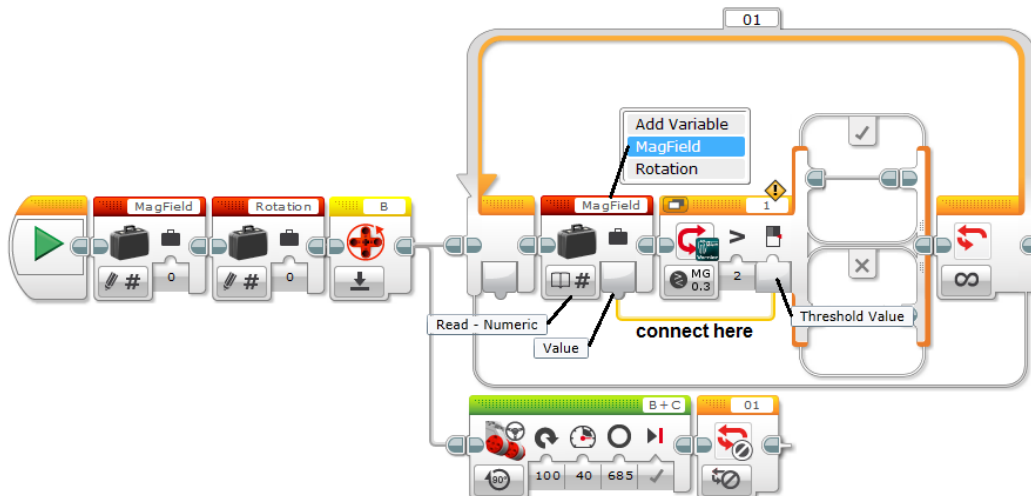
Configuration settings for resetting the rotation sensor

In the next part of the program, two things must happen simultaneously: the robot must continuously take readings from the Magnetic Field Sensor while it is slowly rotating in a circle. This is called *parallel processing*. In order for the two actions to occur at the same time, you must lay down their blocks of code onto separate, but parallel, tracks on the programming canvas. The first action is contained in a Loop block; the second action is performed by a Move Steering block. First lay down a Loop block to the right of the Motor Rotation block. Keep the default mode of Unlimited repetitions. Next position a Move Steering block under the Loop block. To connect the Move Steering block to the program so that two actions form parallel tracks, click on the output node of the Motor Rotation block and drag a wire down to the input node of the Move Steering block. The final step is to configure the Motor Rotation block for turning in a circle. Set the mode to On for Degrees, the Steering to 100, the Power to 40, and the Degrees to 685. (Note: you may need to adjust the number to degrees to ensure that your robot turns completely around.)



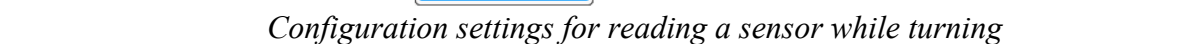
Configuration settings for parallel processing

As your robot turns, it will be searching for the location of the highest magnetic field strength. When the sensor detects a value higher than the current value stored in the MagField variable, the program will replace that value with the latest sensor reading. Place a third Variable block inside the Loop. Click on the text box and select MagField from the pop-up list of variable names (Note: you are not creating a new variable, but using one you have already made). Set the mode to Read » Numeric. Next place a Switch block to the right of the Variable block. Set the mode to Vernier » Compare » STEM 2 Sensors » Magnetic Field 0.3 mT, and the Compare Type to 2 (Greater Than). Be sure the port number matches the port into which you plugged the Magnetic Field Sensor. Connect the two blocks together by dragging a wire from the Value box on the Variable block to the Threshold Value box on the Switch block.



Using a Variable as a threshold comparison for a Switch block

If the Magnetic Field Sensor reading is greater than the value in its variable, you want to store both the Magnetic Field and rotation sensor readings into their respective variables. These actions are performed in the True case of the Switch block. If the sensor value is less than the variable value, then you want to take no action and the False case should remain empty. Place a Vernier Sensor block in the True case of the Switch block. Set the mode to Measure » STEM 2 Sensors » Magnetic Field 0.3 mT and the Port to 1. Place a Variable block to the right of the Vernier Sensor block. Set the mode to Write » Numeric, and then click on the text box and select MagField from the pop-up list of variable names. Wire the Value boxes of both blocks together. Next, place a Motor Rotation block next to the MagField Variable block. Set the mode to



Solar Panels

Task

Build a robot that will keep a pair of solar panels pointed toward a light.

Objectives

- Learn how a solar panel works
- Measure the electrical output from a solar panel
- Investigate how the solar panel's orientation angle affects its electrical output
- Measure the electrical output when multiple solar panels are connected together
- Wire an electrical circuit
- Build and program a robot to follow a light source

Vocabulary

- clockwise
- counterclockwise
- orientation angle
- photovoltaic cell
- resistor
- semiconductor
- solar

Materials (for each team)

- LEGO robotics kit
- Differential Voltage Probe (Vernier DVP-BTA)
- NXT Sensor Adapter (Vernier BTA-NXT)
- (2) Solar Mini Panels – 2V, 200mA, $2\frac{5}{8} \times 3\frac{3}{4}$ " (Pitsco W56852)
- (2) 100-ohm resistors
- hook-and-loop tape
- protractor
- tape
- engineering notebook
- (2) pencils

Preparation

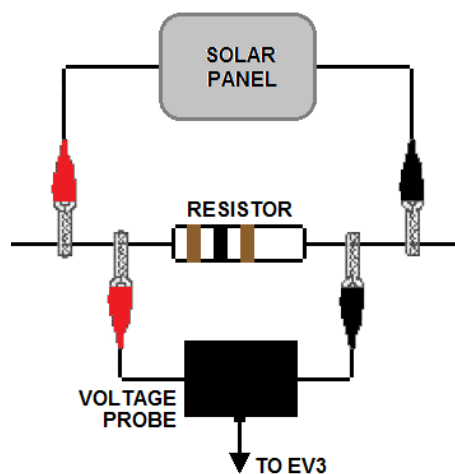
1. Tape a pencil to the back of each solar panel. The pencil will serve as an axis of rotation.
2. Optional: Build an attachment for two solar panels and a voltage probe according to the *Solar Panel Holder* and Voltage Probe Holder building guides found in *Appendix C* to use as a demonstration example.

Order of Activities

1. Explain how a solar panel works. Ask if students have seen a solar electrical or heating system in operation. (10–25 min)

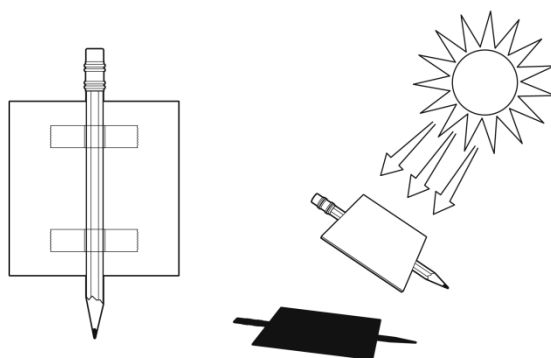
Field Trip Extension: Visit a solar installation on your campus or in a nearby neighborhood.

2. Have students modify and download the *Vernier Data Display* program so they can use the Differential Voltage Probe to measure electric potential. (10–15 min)
3. Connect a resistor to the alligator clips on the voltage probe and one solar panel as shown in the wiring diagram below. Note: Resistors do not have polarity so they can be connected in either direction. (10–15 min)



Wiring diagram for a solar panel

4. Have students aim the solar panel at the sun and then measure the electrical output at various angles. Assume the solar panel is at 0° when it is pointed directly at the sun. (Tip: To safely aim the solar panel toward the sun, hold the ends of the pencil in your hands and tilt the solar panel toward the sun. The pencil should be perpendicular to the incoming ray of sunshine. Find the shadow of the solar panel and observe how it changes shape as you move the pencil. Rotate the pencil until the shadow from the solar panel becomes a small rectangle. This indicates that the solar panel is now pointing directly at the sun.) (10–20 min)



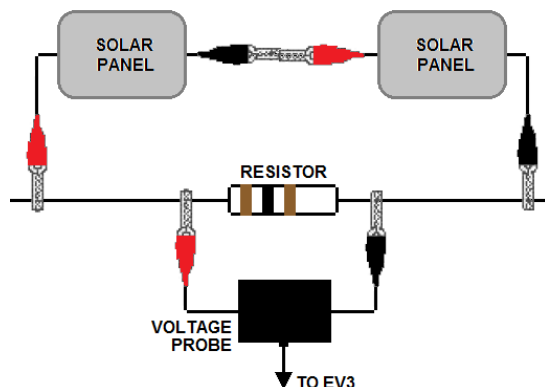
Orientation for aiming the solar panel directly at the sun

5. Discuss how a solar panel's orientation angle toward the sun affects its electrical output. (10-20 min)

Meteorology Extension: Look up the average monthly sunlight level for your area. This average should take into account rainfall and cloudy days.

6. Have students measure and compare the electrical output from their solar panels when two panels are connected together. Connect the black alligator clip of one solar panel directly to the red clip of a second solar panel. (10–20 min)

Math Extension: Calculate the number of solar panels that would be needed to recharge the battery on a NASA rover. Assume the rover uses a 12-volt battery.



Wiring diagram for two solar panels in series

7. Discuss the influence of geographic location and seasons of the year on solar energy production. (10–20 min)

Research Extension: Log on to the Vernier website (www.vernier.com) and compare the solar energy production in Portland, Oregon for the past 24 hours. Download the *Solar Information and Activities* file to find data for an entire year.

8. Have students design and build an attachment for two solar panels similar to the model in the *Solar Tracker* building guide found in *Appendix C*. Let teams work at their own pace giving verbal guidance only when asked. (30–55 min)
9. Have students write a program to make the robot pivot left or right in order to keep the solar panels pointed toward a light. (20–40 min)

Robot Educator Tutorial: This activity requires that you use readings from the Differential Voltage Probe to determine the direction of the robot's rotation. If your students need a little additional programming instruction, have them work through Tutorial #3, *Curved Move*, in the Basics section of the Robot Educator. This tutorial teaches students how to use the Move Steering block to rotate the robot clockwise or counterclockwise.

10. **Challenge for Early Finishers:** Add the gyro sensor to the robot. Write a program to display the robot's angle and the electrical output from one solar panel as the robot slowly pivots in a complete circle.

Background

A solar panel is a group of photovoltaic cells connected together and packaged into a frame. *Photovoltaic (PV) cells* convert light into electricity. They are made from crystalline silicon, a well-known semiconductor used extensively in electronic circuits. When light strikes a PV cell, the absorbed energy knocks electrons loose allowing them to flow freely. The more light that is absorbed by the solar panel the more electrons that are knocked loose and the stronger the electrical current.

Solar panels have a maximum voltage rating just like batteries; but unlike batteries, solar panels have no storage capacity. When no light strikes them, they cannot produce electricity even if a load is connected. Solar panels can be connected together in series to increase their voltage

output just like regular batteries—the positive terminal (red wire) in one panel is connected to the negative terminal (black wire) in a second panel.

The amount of light that falls on the Earth is enormous, but not all light actually reaches the surface. About a third is reflected back into space and some is absorbed by the atmosphere. The time of day and seasons of the year affect the angle that the sun's light strikes the Earth. For maximum effectiveness, solar panels are usually tilted at an angle as close to the area's latitude as possible to absorb the greatest amount of energy year-round. Mounting solar panels on a tracking device has the added benefit of adjusting the orientation angle to coincide with the position of the sun at various times of the day and/or year.

The electrical demand for a house is strongly dependent on the weather, because in most homes the HVAC (heating, ventilation, and cooling) system constitutes the largest portion of the home's energy costs. Winter and summer temperatures require high heating and cooling loads. Many people store excess solar energy in batteries or use a backup generator to produce extra energy for times when the sun is not shining. Other people connect their homes to the utility grid, buying power when it is needed and selling it back when they produce more than they can use.

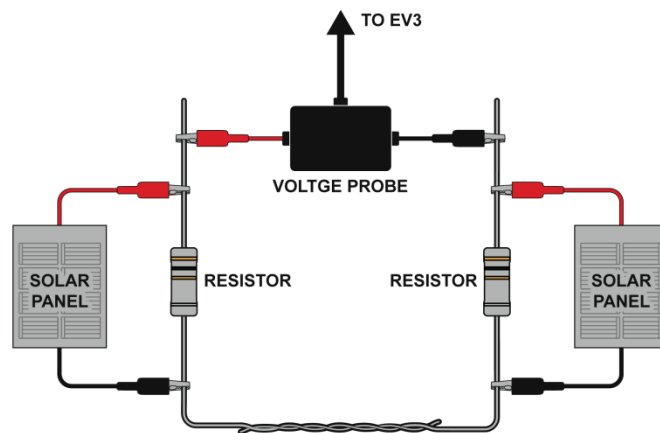
Fun Fact

Curiosity's predecessors, the Spirit and Opportunity rovers, used solar power. They absorbed the sun's energy through solar panels attached to the top of their driving bases. Since the intensity of the sun is weaker on Mars than it is on Earth, the panels were designed to maximize the area of solar cells that collected the sun's energy. The panels were made up of three layers of solar cells allowing them to absorb significantly more sunlight than the single-layer panels used on previous missions. Both rovers carried two 8-amp-hour rechargeable lithium batteries. While an inexpensive and renewable energy source, solar power has some shortcomings for planetary exploration. Rovers using solar power cannot work at night when the sun goes down. Rovers cannot explore in the shadows of mountains or craters, nor can they efficiently explore the area near the poles during the off season. Solar power limits the places that rovers can land on Mars and panels tend to lose their efficiency when covered with Martian dust. Consequently, solar panels were not chosen as the power source for the Curiosity rover. However, both Spirit and Opportunity far exceeded their 90-day mission expectancies. Spirit continued to operate until the spring of 2010; Opportunity is still driving around Mars today.

Sensor Notes

In this activity, you will use a Vernier Differential Voltage Probe to measure the voltage generated by two solar panels when in the presence of a strong light source. Your robot should be able to rotate 360° in both the clockwise and counterclockwise directions so that the light is always centered between the pair of solar panels. The panels should be securely mounted to the robot but at a slight offset to each other so that they form an angle of about 160°.

The simplest way to take measurements from two solar panels is to use two voltage probes and have the robot rotate toward the panel with the highest voltage reading (the panel with more light falling on it). However, since you are limited to one voltage probe, there is a way to connect the solar panels together to get the same effect as shown in the diagram.

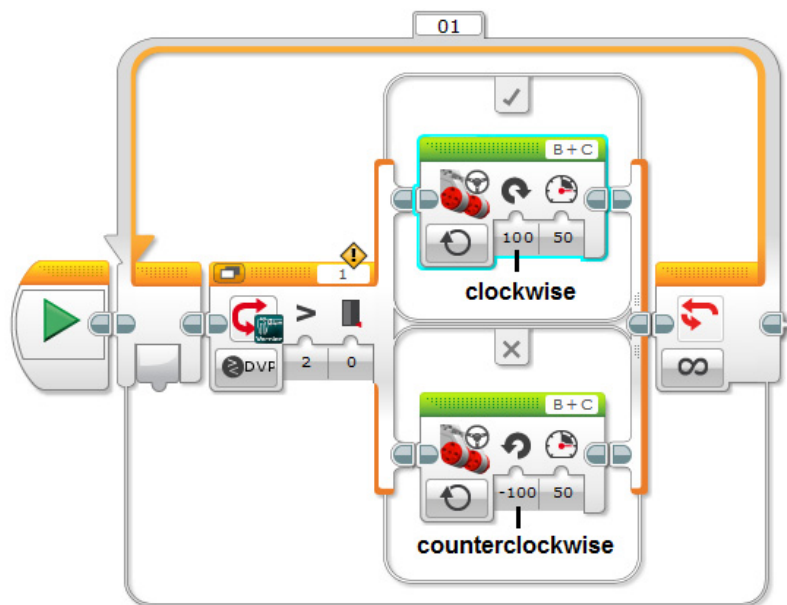


Wiring diagram for a solar tracker

First, twist the wires from two 100-ohm resistors together. A *resistor* is an electronic component that limits the current that flows through the solar panels. Twisting the wires together forms a connection called a *common ground*. Next, connect the two clips on the voltage probe to the free wires on the resistors. The clips can be connected in any order. The final step is to connect the solar panels to the resistors. The red clip on the solar panel should be connected to the free wire on the resistor and the black clip should be connected to the common ground wire. When mounting the solar panels onto the robot, be sure that the resistor wires do not touch each other or the voltage probe may not work.

Programming

Your task is to keep the two solar panels centered on the light source. With both solar panels wired to one voltage probe, the readings from the voltage probe will be negative if one solar panel is getting the most light and positive if the other solar panel is getting the most light. A simple program showing how to control the direction of rotation based on the voltage reading is shown below.



Sample program for a solar tracker

Since you want this program to run continuously, the first block you should lay down onto the programming canvas is a Loop block. Keep the default mode of Unlimited repetitions. Next you will need to take a sensor reading from the voltage probe and compare it to a threshold value for distinguishing a positive reading from a negative reading. Place a Switch block inside the Loop block. Set the mode on the Switch block to Vernier » Compare » STEM 2 Sensors » Voltage. Be sure the Port Number on the Switch block matches the port in which you plugged the Differential Voltage Probe. Adjust the Comparison type to 2: Greater Than and enter a threshold value. Normally you would enter a zero for the threshold value, but since the EV3 Vernier Sensor Block does not have a Zero function, you should enter the offset value you found in Day 2.

Place Move Steering blocks in both the True and False cases. Set the mode to On and the Power to 50. One Move Steering block will cause a clockwise rotation and other a counterclockwise rotation, so set the Steering to positive 100 in one case and negative 100 in the other case. (Note: flip the Steering values in the True and False cases if your robot is turning the wrong way.)

Martian Challenge

Task

Build a robot to retrieve two stranded astronauts on Mars, replace dead batteries with fresh ones, remove dust from solar panels, and find magnetic rocks scattered near the base station.

Objectives

- Learn how to write pseudo code
- Develop a strategy for performing multiple tasks in a limited timeframe
- Learn how to create a My Block
- Investigate using multiple sensors concurrently

Vocabulary

- maneuver
- multitask
- navigate
- odometry
- pseudo code
- strategy

Materials (for each team):

- LEGO robotics kit
- tape measure or ruler
- dark tape (i.e., black electrical tape or blue painters tape)
- Post-it[®] notes or small slips of paper
- engineering notebook
- pencil

Materials (for field setup)

- dark tape (i.e., black electrical tape or blue painters tape)
- tape measure or ruler
- 2 solar panels
- 2 LEGO minifigures
- 3 neodymium disc magnets
- 4 fresh batteries
- 2 dead batteries
- miscellaneous LEGO building components

Preparation

1. Outline a playing field with dark tape according to the measurements in the *Field Setup Guide (Appendix D)*. The playing field can be located on a large table top or the floor.
2. Build two solar panel holders from miscellaneous LEGO building components. Use double-sided tape to adhere the solar panels to the holders. Secure the lead wires to the underside of

- the holder with tape. Position the holders as shown on the *Field Setup Guide (Appendix D)*. Place four LEGO 2×2 bricks on top of each solar panel.
3. Build four battery holders and position them on the playing field as shown in the *Field Setup Guide (Appendix D)*. Randomly place two fresh and two dead batteries into the holders on the playing field and place the remaining two fresh batteries in the Home Base area.
 4. Place six LEGO 2×8 bricks on the playing field as shown in the *Field Setup Guide (Appendix D)*. Randomly hide three neodymium disc magnets under three of the bricks.

Order of Activities

1. Explain the rules of the challenge and the scoring system. (10–20 min)
2. Explain the concept of pseudo code. (10–20 min)
3. Hand out Post-it notes or small slips of paper and have students brainstorm their initial strategies using pseudo code. Have students summarize their strategies in their engineering notebooks. (10–20 min)
4. Demonstrate how to create a My Block. (10–15 min)
Robot Educator Tutorial: This activity requires that students learn to group multiple programming blocks into a single block. If your students need a little additional programming instruction, have them work through the *My Blocks* tutorial in the Tools section of the Robot Educator.
5. Give students ample time to program and test their strategies before conducting the competition. Allow them to make modifications to their robots and/or make new attachments as desired. (55–115 min)
Robot Educator Tutorial: This activity requires that the robot perform multiple moves within a short timeframe. If your students need a little additional programming instruction, have them work through Tutorial #1, *Multitasking*, in the Basics section of the Robot Educator.
6. Conduct a competition to see which robot can accomplish the greatest number of tasks during the 2-minute timeframe. (25–40 min)

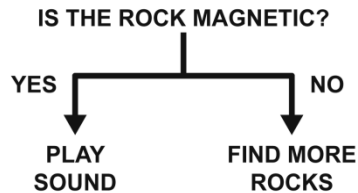
Background

Many programmers jump right into code development without thinking through their strategy or logic—how they are planning to tackle the challenge. *Pseudo code* is a useful technique to help you plot out the actions of your robot. It is not tied to any specific programming language, but uses common words to describe actions. Remember, your robot cannot think for itself, nor can it read your mind. It will only do what you tell it to do.

The easiest way to start using pseudo code is to write down each action your robot must perform on a separate piece of paper. Sticky notes or index cards work well for this task. Each action should be briefly described with a verb and an object or adverb modifier. For example, some typical robot actions might be Move Forward, Raise Arm, Turn Right. Each individual action should be written on its own slip of paper. You should never use more than one verb, nor should you use connector words, such as “and,” because each action will eventually correspond to an individual block of code.

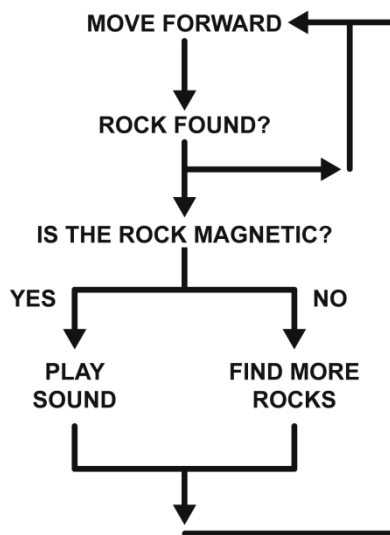
Once you have all your actions written on slips of paper, tape them to a larger piece of paper or to a white board and connect them with arrows. Arrows help to clarify the order in which your actions will be executed. Typically, you should try to arrange your slips of paper so that your arrows always point down or to the left. To keep your logic understandable, never allow your arrows to cross.

Periodically your robot may have to choose between two different actions. In these instances, you will need to insert a question into your pseudo code. For example, in this activity you want your robot to find rocks and determine if they are magnetic. Remember, your robot cannot think for itself, so when you ask a question, it is very important that you phrase it in such a way as to return a “yes” or “no” answer. For example, “Is the rock magnetic?” In your program, this question corresponds to a Switch block. The program will take a reading from the magnetic field sensor and compare that reading to a threshold value – for example, is the magnetic field strength greater than 3 mT. If the answer is yes, then the program will know the rock is magnetic and will tell the robot to play a sound. If the answer is no, then the program will tell the robot to search for another rock.



Pseudo code for determining the status of a rock

Sometimes you may want to repeat an action or a group of actions. Rather than write them out on multiple slips of paper, you can use arrows to redirect the flow and repeat an action. This corresponds to a Loop block. In the program above, you want the robot to keep moving forward until it comes to a rock, so the “no” response to the question is actually just to keep moving forward. Once your robot has found a rock and determined its status, you want to repeat the entire set of actions over again; hence the long upward arrow on the right side of the drawing.



Pseudo code for finding magnetic rocks

Once you have your pseudo code written down, you should test it out by reading off each step to your partner as he or she pantomimes the actions. Remember, a robot will do exactly what you tell it to, so try to think of this activity as the *Simon Says* game—if Simon does not say to stop, you cannot stop. This can help you quickly identify inconsistencies or errors in your logic.

Using sensors rather than dead reckoning will ensure that your program is not dependent on a particular playing field but can navigate a variety of different layouts. Many students tend to rely on time or odometry to move their robots a specific distance. *Odometry* uses feedback from the

rotation sensors to move your robot a certain number of degrees or rotations. With this method, the robot's position is always relative to its starting point. A smart robot uses sensors to analyze where it is in relation to various targets. For example, combining LEGO's Color Sensor with the Vernier Magnetic Field Sensor can help you find rocks and then determine if they are magnetic.

Rules of the Game

The Martian challenge is played on competitive playing field with one robot on the field at a time. Students must program their robots to complete as many tasks as possible within a 2-minute timeframe.

- **Retrieve two stranded astronauts.**

The robot may use any method to retrieve the LEGO astronaut minifigures (pushing, pulling, picking up, etc). The robot can retrieve both astronauts on one run or each astronaut on a separate run. Note that BOTH the astronaut and the robot must cross the Home Base line. If the robot drops or loses control of the astronaut on the way back to base or if a student touches the robot before the astronaut has crossed the Home Base line, the astronaut will remain on the field where this occurred.

- **Replace dead batteries with fresh ones.**

Students must use a Vernier Differential Voltage Probe to prove to the referee that a battery is dead. Measurements can be taken by the robot on the playing field or by the student after a battery is brought back to base by the robot. The referee will declare the battery as dead if the voltage reading on the EV3 Brick is less than 1.2 volts. At that point, the dead battery can be replaced with a fresh one from the Home Base area. Note that robots may bring the battery and its holder back to base so that the student can perform the measurement and replacement by hand, and then the robot can return the battery and holder to its original position (± 6 inches). If the robot drops or loses control of the battery holder on the way back to base or if a student touches the robot before the battery holder has crossed the Home Base line, the battery holder will remain on the field where this occurred. All batteries must be in their holders to score.

- **Remove dust from the solar panels.**

Robots must remove the dust (2x2 LEGO bricks) from the solar panels without tipping the panels over or without bringing the panels back to base. Solar panels should remain in their original position (± 6 inches). A dust brick must be touching the playing field to score. Solar panels that have been tipped over will incur a penalty.

- **Find magnetic rocks scattered near the base station.**

Students must use a Vernier Magnetic Field Sensor to prove to the referee that a rock is magnetic. Robots must be within 6 inches of a magnetic rock (2x8 LEGO brick) with the tip of the sensor pointing towards the rock when they sound an alert for the referee. Robots should pause for 2 seconds to give the referee time to check the status of the rock, and then return to Home Base or continue onto the next task. Magnetic rocks may not be brought back to Home Base and should, in general, not be disturbed by the robot. Sounding an alert for a rock that is not magnetic will incur a penalty.

All robots must start completely behind the lines of the Home Base area. The only time students are allowed to touch their robots without incurring a touch penalty is when the robot is in Home Base. Once students have pressed the Center Key to start program execution, they may not touch

their robots again until the robot returns to base. Any part of the robot crossing one of the dark lines counts as the robot being in base.

Points are awarded for the successful completion of each task as described in the Scoring Table below.

Task	Points	Total Points Possible
astronauts in base	10 ea	20
voltage measurement on battery	15 ea	60
replace dead battery with fresh battery	20 ea	40
remove dust brick from solar panel	5 ea	40
sounding an alert for a magnetic rock	20 ea	60

Penalties	Points	Total Points Possible
touching the robot outside of Home Base	-5 ea	-40
“good” battery holder not in original position	-10 ea	-20
solar panel overturned	-20 ea	-40
sounding a false alert for a magnetic rock	-10 ea	-30

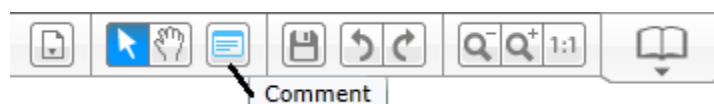
Touch Penalty: There will be times when the robot gets stuck or does not perform as expected on the playing field. In those situations, the student may bring the robot back to base and try again. However, touching the robot when it is not in Home Base will incur a penalty. The referee will remove one dust particle from the ground (the one 2×2 brick farthest away from Home Base is preferred). If there are no dust particles on the ground, the referee will remove one dust particle from a solar panel.

As the teacher/referee, you should feel free to amend the rules of the game to suit your particular situation. However, try to be as clear as possible right from the start on your expectations for your students. Try to identify any misinterpretation of the rules during the students’ strategy session. Avoid making changes on the fly as this can lead to frustration and hard feelings among teams. If time permits, allow students to compete multiple times and improve their initial score. Above all, have fun. After all the hard work to get to this point, you want your students to end on a positive note with a feeling of accomplishment.

Programming

When developing a complex program it is often helpful to group blocks of code together. In traditional software programs, these blocks of code are called *subroutines*; within the EV3 software, these groupings are called *My Blocks*. This technique not only aids in readability, but it reduces the memory requirements on the EV3 Brick. It also provides a simple way to re-use blocks of code throughout different parts of your program.

Adding comments periodically to your code is another useful tool that helps in understanding the logic of your program. You can insert a text box for comments by clicking the Comment button in the upper right menu on programming sheet.



Comment tool for documenting programs

Sensors and Materials

This unit on electricity and magnetism was developed for LEGO's new EV3 robotics system and software introduced in 2013. It was written with the Education version, but it will work equally well with the commercial set. You can purchase the EV3 Core Set (order code W5003400) and EV3 Software (order code W2000045) directly from LEGO Education. The commercial building set can be purchased from Amazon.com or any toy store. The EV3 software for the commercial set is a free download from the LEGO.com website. Be aware that the commercial software does not include the Data Logger for graphing sensor input.

Users of the older NXT robotics system and software can perform most of the activities in this unit with only slight modifications. Sample programs for each activity are given in *Appendix E*.

You will need a Differential Voltage Probe, a Magnetic Field Sensor, and an NXT Sensor Adapter from Vernier Software & Technology to perform the electricity and magnetism activities covered in this unit. These products are described in the table below.

Vernier Products Used in this Unit			
Item	Day	Order Code	Description
Differential Voltage Probe	2,4,5	DVP-BTA	Measures electrical potential with a range of ± 6 volts.
Magnetic Field Sensor	1,3,5	MG-BTA	Measures magnetic field intensity in two ranges: high amplification (0.32 mT) for measuring the Earth's magnetic field and low amplification (6.4 mT) for measuring permanent magnets.
NXT Sensor Adapter	1–5	BTA-NXT	Used to build sensor-based control systems with Vernier sensors and LEGO MINDSTORMS EV3 or NXT sets. The adapter is compatible with over 30 Vernier sensors, and includes a LEGO socket on one end and a Vernier BTA connector on the other end.

In addition, you will need some specialty equipment to perform several of the activities. A description is given below along with a recommended supplier. Feel free to use a different supplier if you find a better source for a compatible item.

Specialty Items Used in this Unit			
Item	Description	Supplier	Order Code
Bar Magnet	pair	Pitsco	W31889
Neodymium Magnets	0.47" dia x 0.11" thick, pkg of 6	Pitsco	W58804
Safe-T Protractor	6", 180°	Pitsco	W56089
Solar Mini Panel	2V, 200mA, 2 $\frac{5}{8}$ " x 3 $\frac{3}{4}$ " with alligator clips	Pitsco	W56852
Resistor	100-ohm, 1/8-watt carbon film, pkg of 6	Radio Shack	271-005
Map Compass	5 $\frac{1}{2}$ " x 2 $\frac{3}{8}$ ", 360° x 2° increments	Science Lab Supplies	1405-50

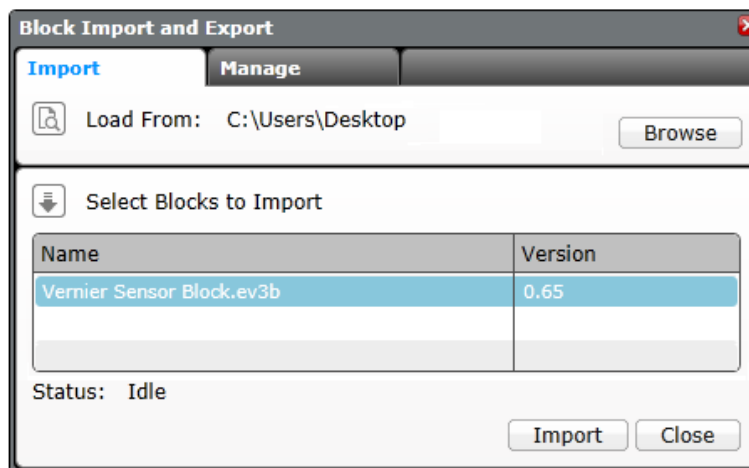
The following table lists the items you will need to conduct the activities in this unit. The amounts listed are for one work group. Many of these items can be purchased at your local hobby or home improvement store. Be aware that a few items are consumable (such as tape), so if you are conducting the unit multiple times you will need to duplicate the amount on those items.

Materials Used in this Unit		
Item	Amount	Day
battery – AA fresh/new	4	2, 5
battery – AA used/worn out	2	2, 5
battery – AAA fresh/new	1	2
battery – C fresh/new	1	2
battery – D fresh/new	1	2
compass – field orienteering map	1	3
hook-and-loop tape	4 in	4, 5
iron filings	1 Tablespoon	3
LEGO robotics kit	1	1–5
magnet – bar	2	1, 3
magnet – neodymium disc	2	5
paper clips – metal	10	1, 3
paper clips – plastic	10	1
pencil	1 per student	1–5
protractor	1	3, 4
resistor – 100 ohm	2	4
ruler – 12"	1	2, 3
sandwich bag – clear, re-sealable	1	3
solar mini panels – 2V, 200mA	2	4, 5
tape – clear	12 in	4
tape – dark (electrical or painters)	10 ft	1, 5
tape measure – 10 ft (teacher only)	1	5
Vernier Differential Voltage Probe	1	2, 4, 5
Vernier Magnetic Field Sensor	1	1, 3, 5
Vernier NXT Sensor Adapter	1	1–5

Importing the EV3 Vernier Sensor Block

To use Vernier sensors with the EV3, you will need to import the Vernier Sensor Block into the EV3 software on your computer. This is a free download from the Vernier website (www.vernier.com), and it works with both Windows and Macintosh computers. The Vernier Sensor Block allows you to use Vernier sensors with Loop, Switch, and Wait blocks in the same way you would use LEGO's own sensors. Rather than importing individual blocks for each sensor, however, you simply choose which Vernier sensor you are using from drop-down lists embedded in a single Vernier block. Sensor calibrations are handled automatically with the option to display measurements with proper units.

1. Download the Vernier Sensor Block file from the Vernier website to your computer. This is a compressed .zip file, so the contents must be extracted before importing. Keep note of the location of this file.
2. Start the EV3 software.
3. Open a new or existing program. *Note: You cannot access the Block Import function directly from the software Lobby.*
4. From the menu bar, choose Tools » Block Import.
5. Click the Browse button to locate the Vernier Sensor Block file.



Block Import window

6. Make sure the Vernier Sensor Block.ev3b file is highlighted and click Import.
7. Restart the EV3 software for the change to take effect.

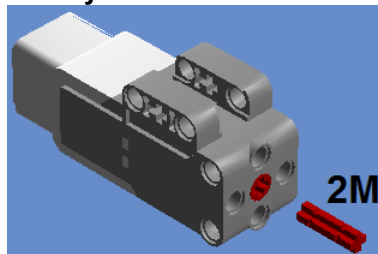
Building Guides for Attachments

The EV3 Educator Vehicle and the attachments shown below were constructed from a single LEGO EV3 Educator robotics kit. Your LEGO robotics kit may differ slightly, especially if you purchased the commercial or the NXT version. Be aware that some of your parts may not exactly match the colors shown in the Building Guides below. The functionality of a particular part, however, is identical. If you find you are missing a particular item, you can usually find something similar to substitute.

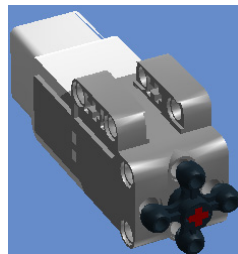
Battery Tester

The Battery Tester will use the Medium Motor to close a pair of gripper arms around the metal terminals of a AA battery. It will be installed on the front of the EV3 Educator Vehicle.

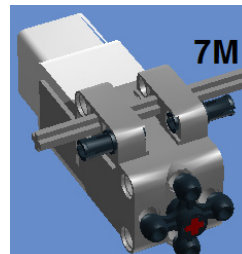
Battery Tester Motor Assembly:



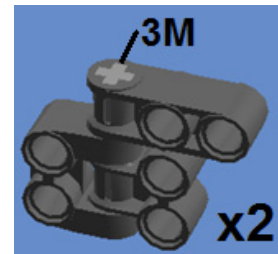
1/19



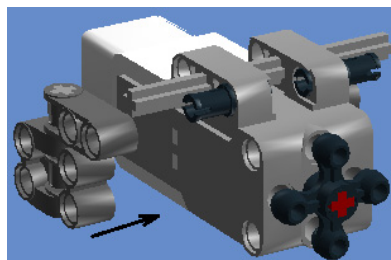
2/19



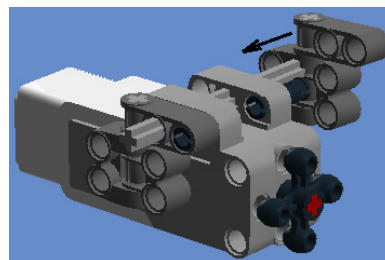
3/19



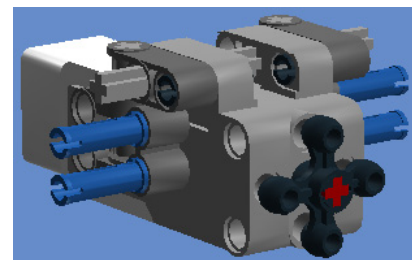
4/19



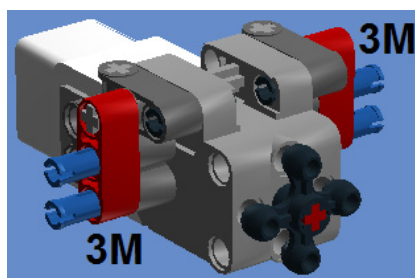
5/19



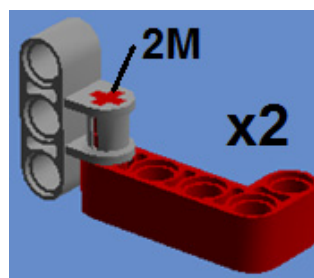
6/19



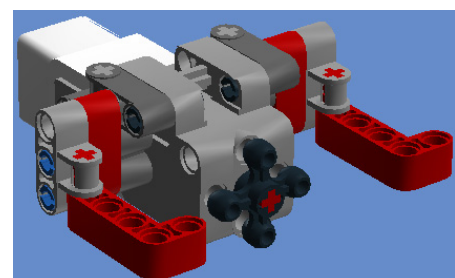
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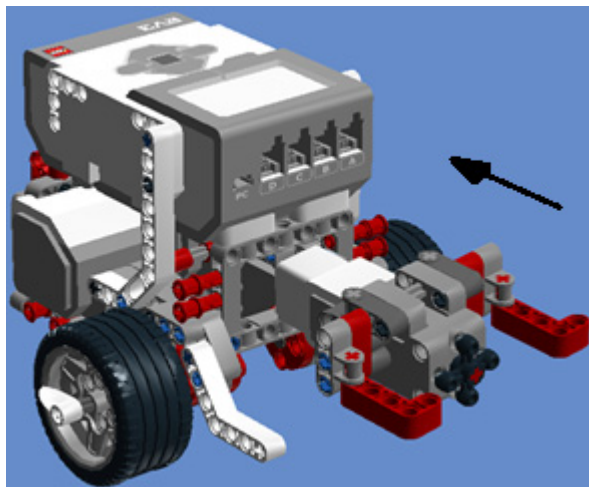


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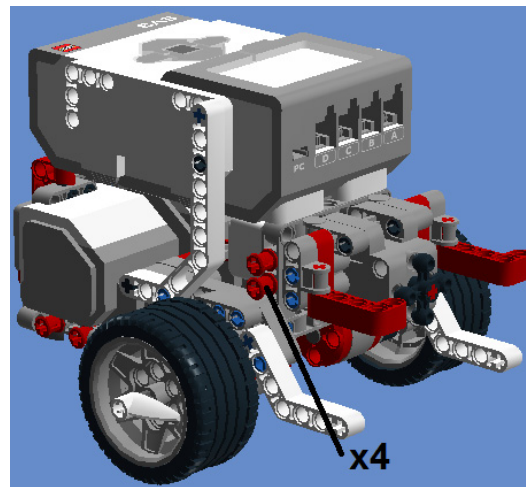


10/19

In Steps 11 and 12, connect a 25 cm cable to the Medium Motor and then insert the Motor Assembly into the rectangular beam frame on the front of the EV3 Educator Vehicle. Secure the assembly to the frame with four push pegs. Connect the Medium Motor to Port A on the EV3 Brick.

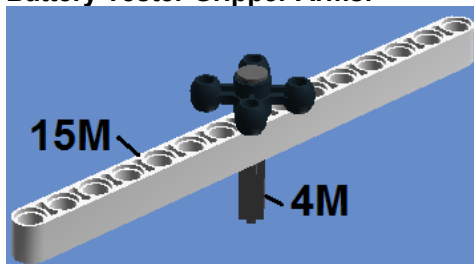


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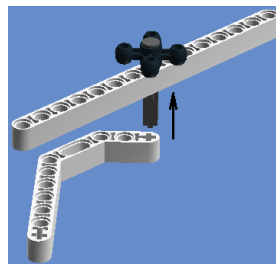


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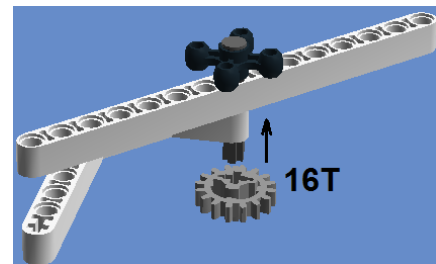
Battery Tester Gripper Arms:



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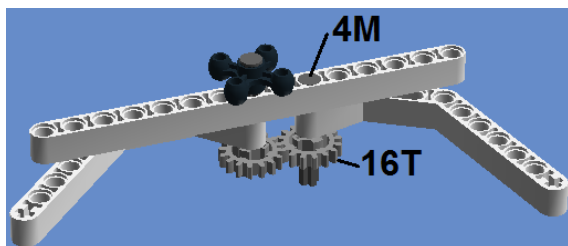


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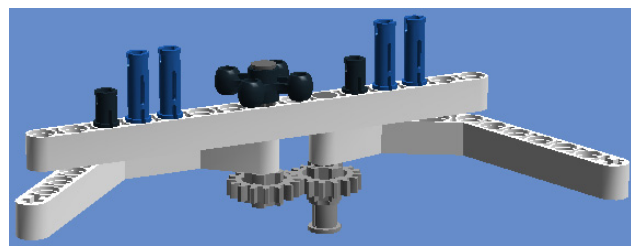


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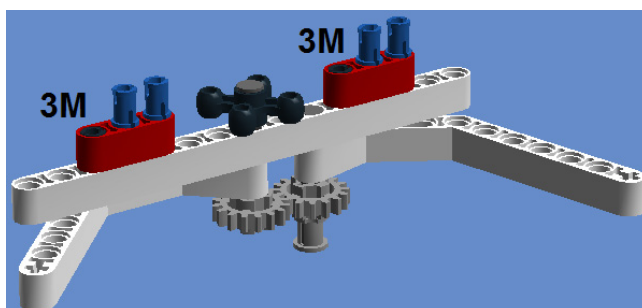
In steps 13 and 16, be sure to use the 4M axles with an end stop. Using regular axles without an end stop may cause the gears to fall off during use.



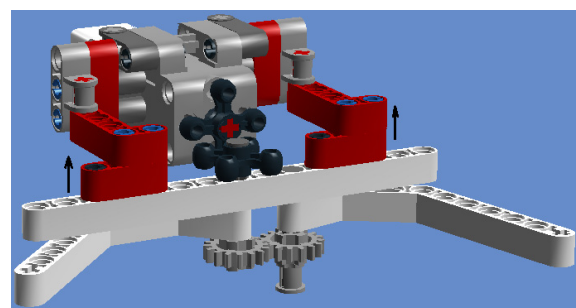
16/19



17/19



18/19

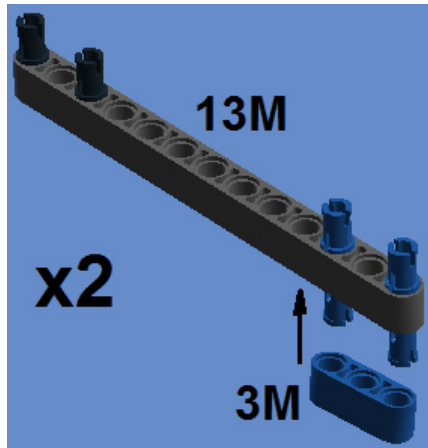


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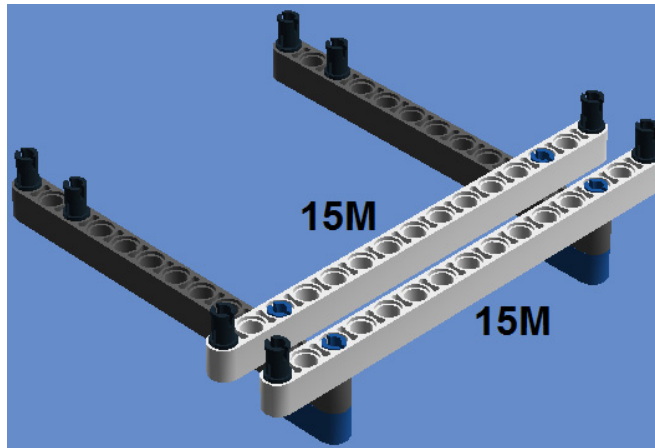
In Step 19, attach the gripper arms to the front of the Motor Assembly by inserting the 3M pegs into the 2×4 90° angular beams.

Battery Tester Base

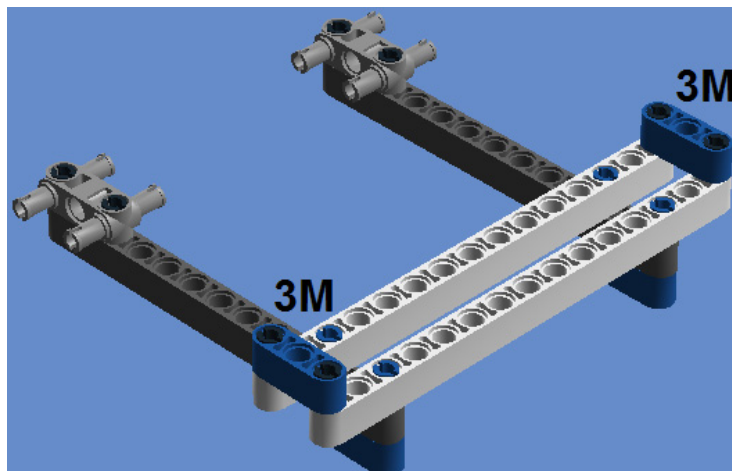
On Day 5, you will be using the Battery Tester as a mobile device in the Martian Challenge. Your robot should be able to drive up to any battery and test it by closing the gripper arms around the battery terminals. However, on Day 2, you will be using the Battery Tester as a stationary device. In this situation, it is more convenient to have a base attached to the front of the robot for holding the batteries in position so the gripper arms can easily lock onto the battery terminals.



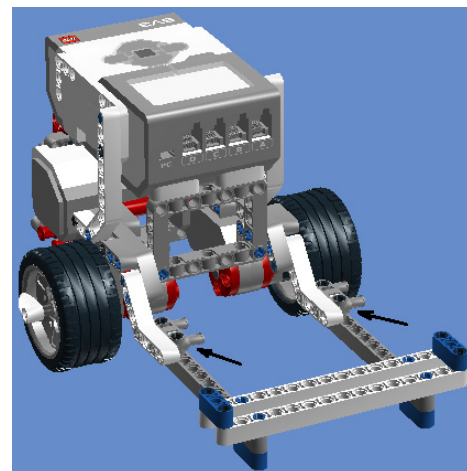
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3/4

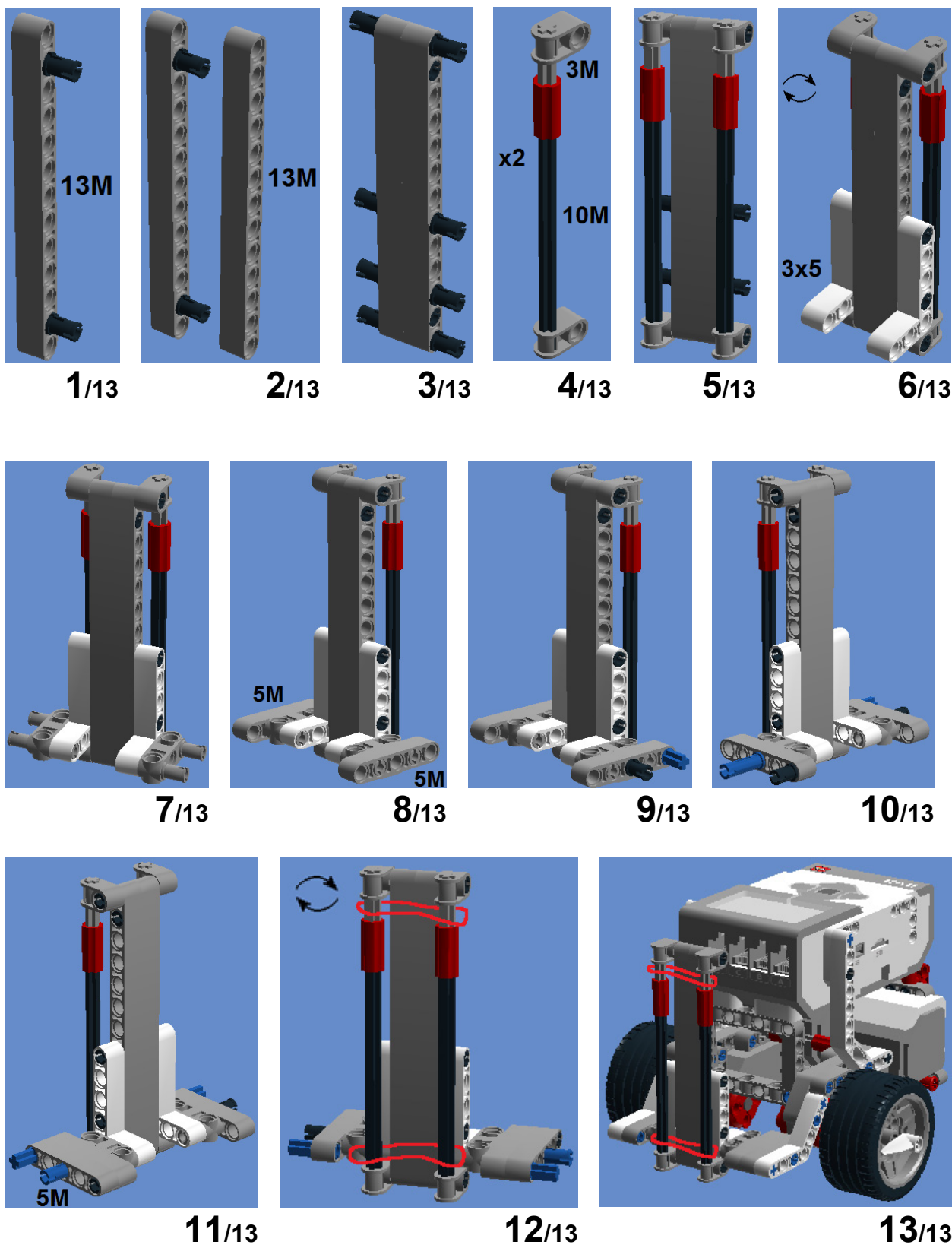


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In Step 4, connect the Battery Tester Base to the right side of the 4×4 angular beams on the front of the EV3 Educator Vehicle (note that the Gripper Arms and Motor Assembly are not shown in this view).

Front Sensor Holder (for Magnetic Field Sensor)

This attachment was designed to secure Vernier sensors with a wand style (such as the Magnetic Field Sensor) to the front of the EV3 Educator Vehicle.

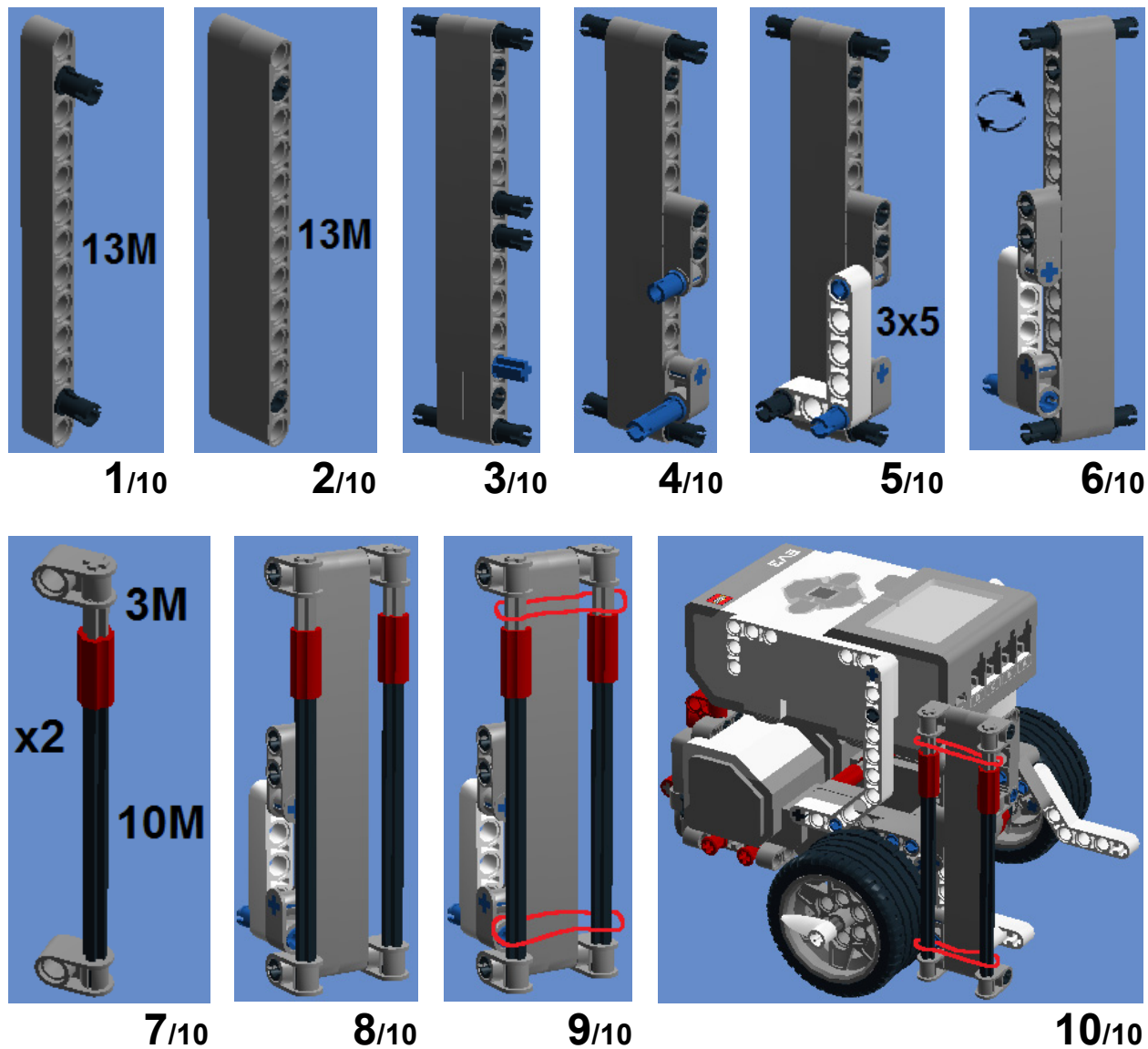


Note that the Front Sensor Holder is not symmetrical. In Step 11 you must add an additional 5M beam so that the sensor holder will fit between the 4×4 angular beams on the front of the EV3 Educator Vehicle. In Step 12, attach rubber bands to the top and bottom axles to hold the shaft of the Magnetic Field Sensor in an upright position. (Tip: To attach the rubber bands, temporarily

slide the axles out of the cross blocks.) In the final step, temporarily disconnect one of the 4×4 angular beams on the front of the robot and attach the Front Sensor Holder to the EV3 Educator Vehicle.

Side Sensor Holder (for Magnetic Field Sensor)

This attachment was designed to secure Vernier sensors with a wand style (such as the Magnetic Field Sensor) to the side of the EV3 Educator Vehicle.



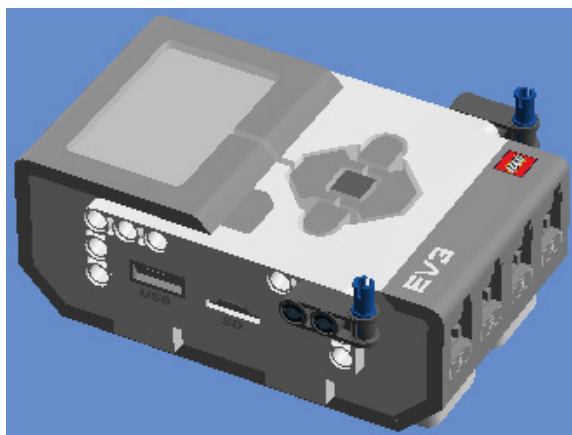
In Step 9, attach rubber bands to the top and bottom axles to hold the shaft of the Magnetic Field Sensor in an upright position. (Tip: To attach the rubber bands, temporarily slide the axles out of the cross blocks.) In Step 10, connect the Side Sensor Holder to the outside of one of the 4×4 angular beams on the front of the EV3 Educator Vehicle.

Solar Panel Holder

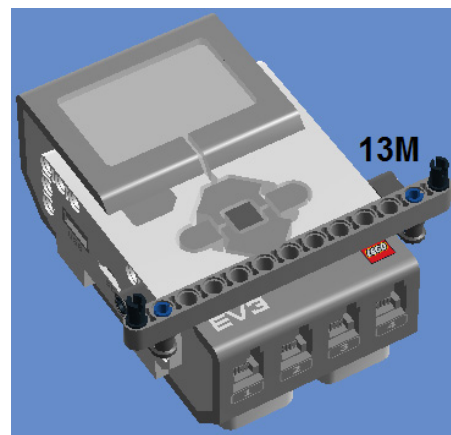
This holder is sized for two 2⁵/₈" x 3³/₄" solar mini panels, such as those sold by Pitsco.



1/10



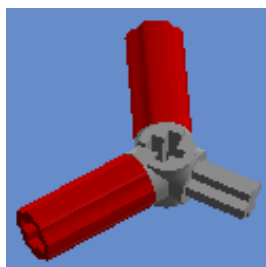
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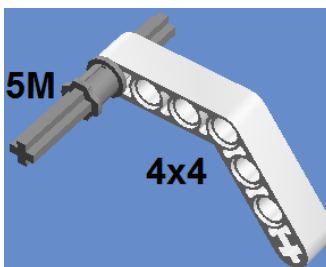
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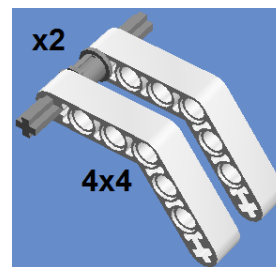
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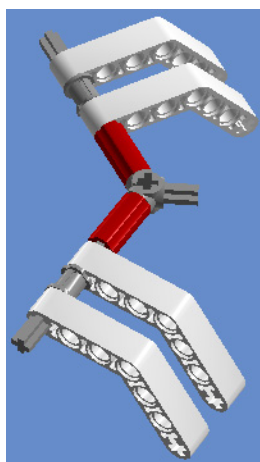
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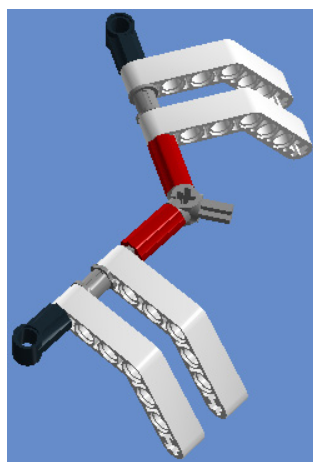
6/10



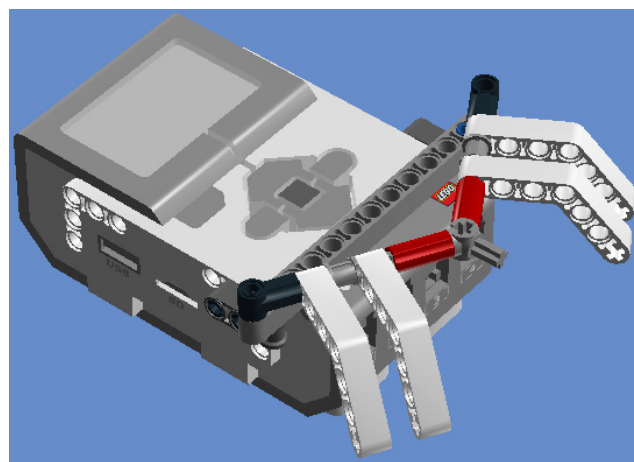
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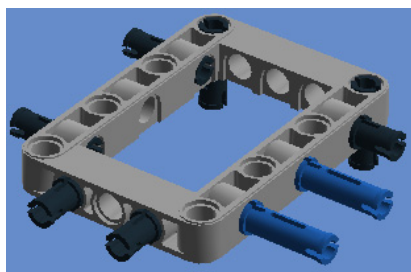


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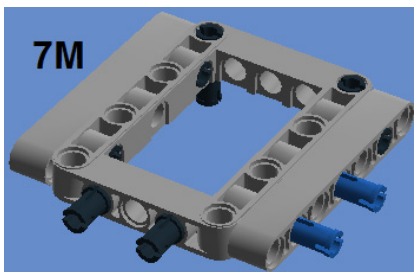
In Step 10, attach the Solar Panel Holder to the 13M beam on the EV3 Educator Vehicle. Attach two solar panels to the 4x4 supports with double-sided tape or a hook-and-loop fastener. Hook-and-loop fasteners have the advantage of making the solar panels easy to remove or reposition.

Voltage Probe Holder

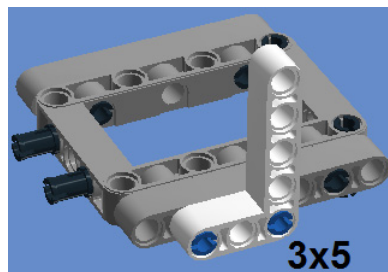
The Voltage Probe Holder is a convenient attachment for concealing the electrical connections beneath the solar panels.



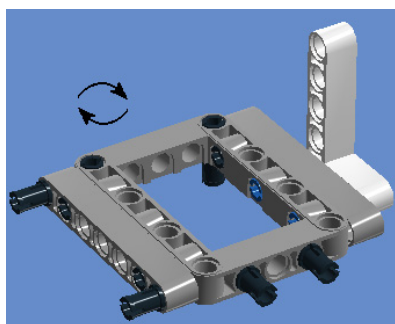
1/8



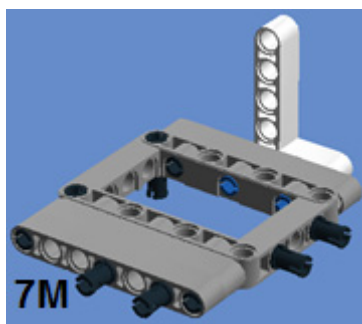
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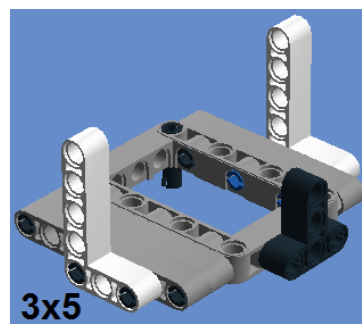
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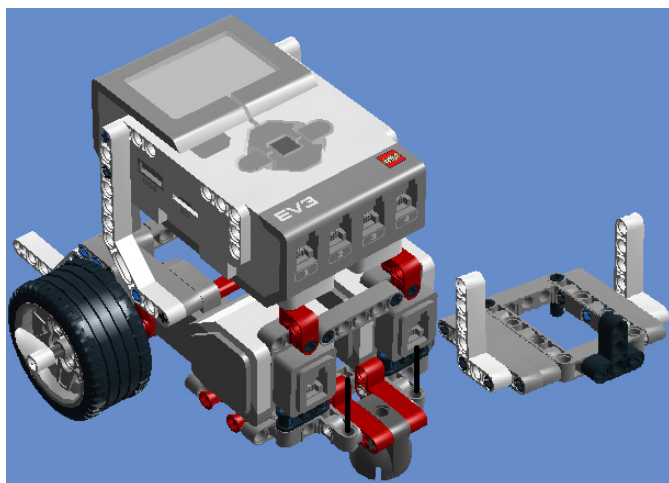
4/8



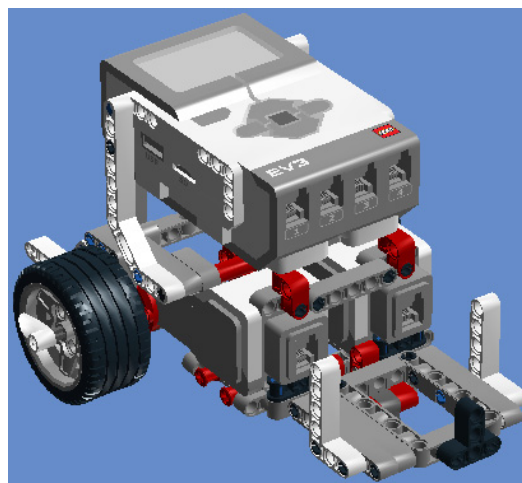
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7/8

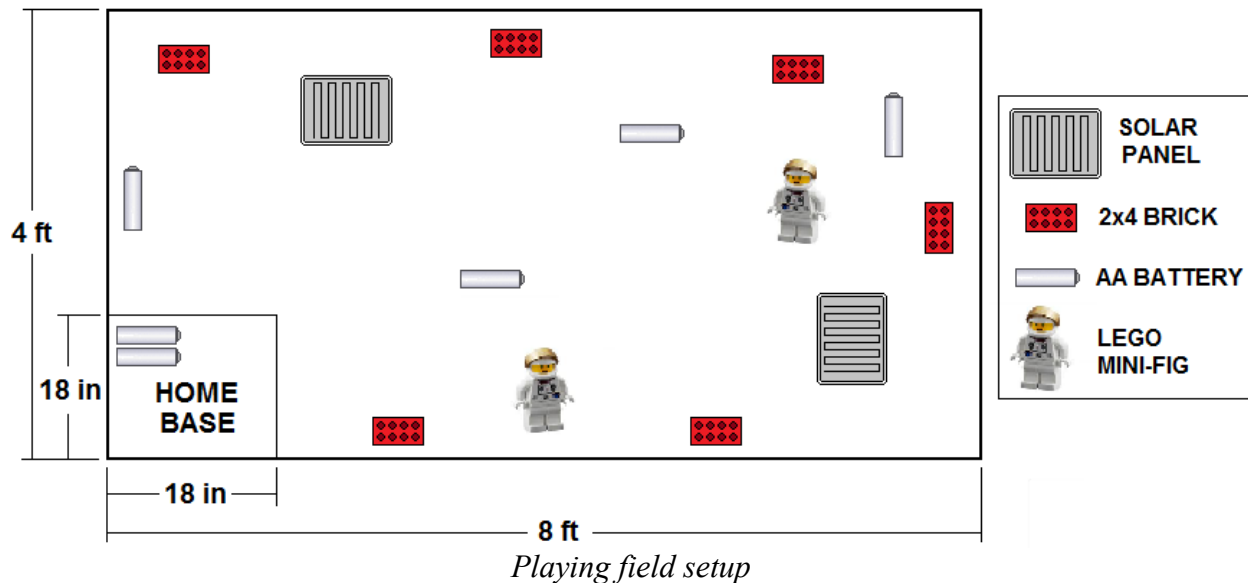


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In the final step, attach the Voltage Probe Holder to the ball caster wheel on the back of the EV3 Educator Vehicle.

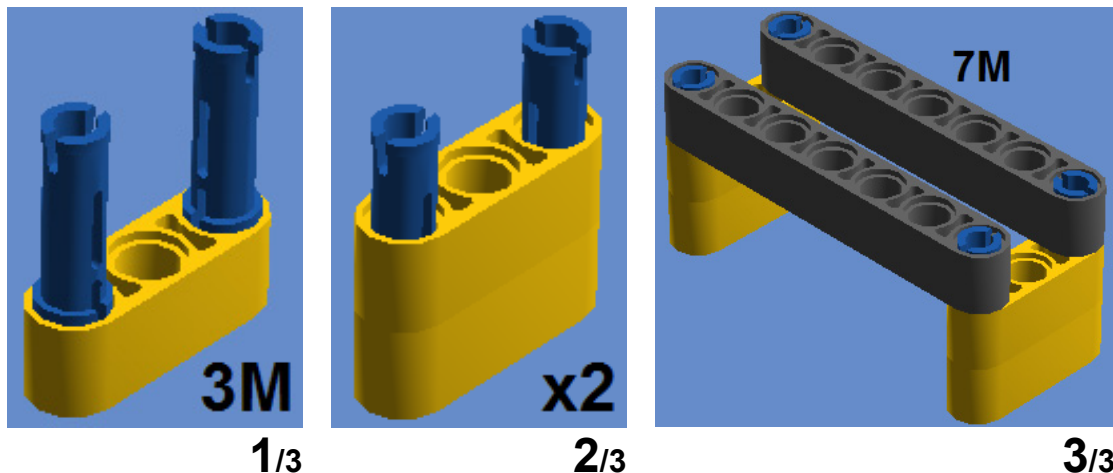
Field Setup Guide

A diagram for the playing field is shown below. This diagram assumes a 4 ft × 8 ft playing field with an 18" × 18" Home Base. Playing pieces are not secured to the field in any way, but once you position them, it is recommended that you mark their original locations with dark tape or a black marker to aid in field reset at the conclusion of each match.

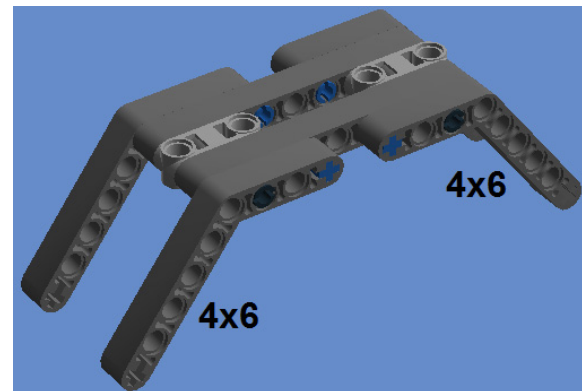
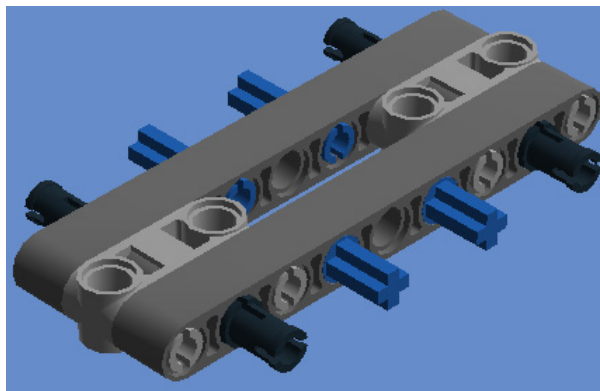
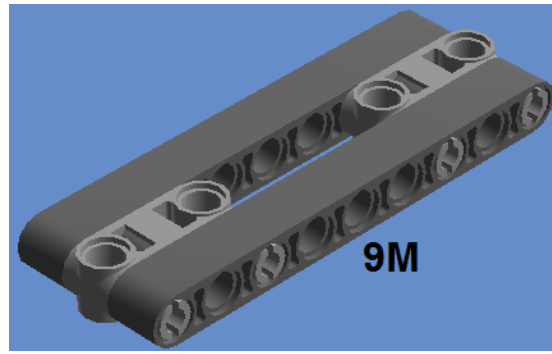
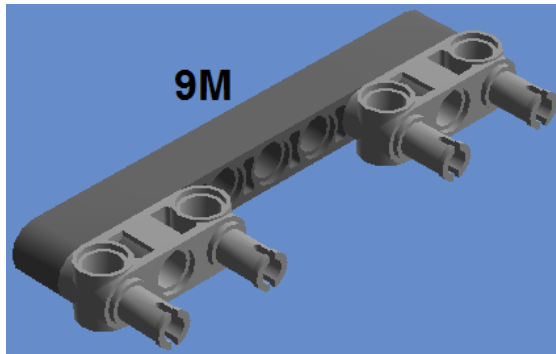


Below you will find the building guides to make holders for the AA batteries and solar panels that will be used in the Martian Challenge. Solar panels should be attached to their holders with double-sided or hook-and-loop tape. Batteries are simply placed in their holders. These guides are merely suggestions. Feel free to make modifications or adjustments as necessary to suit your particular situation.

Battery Holder

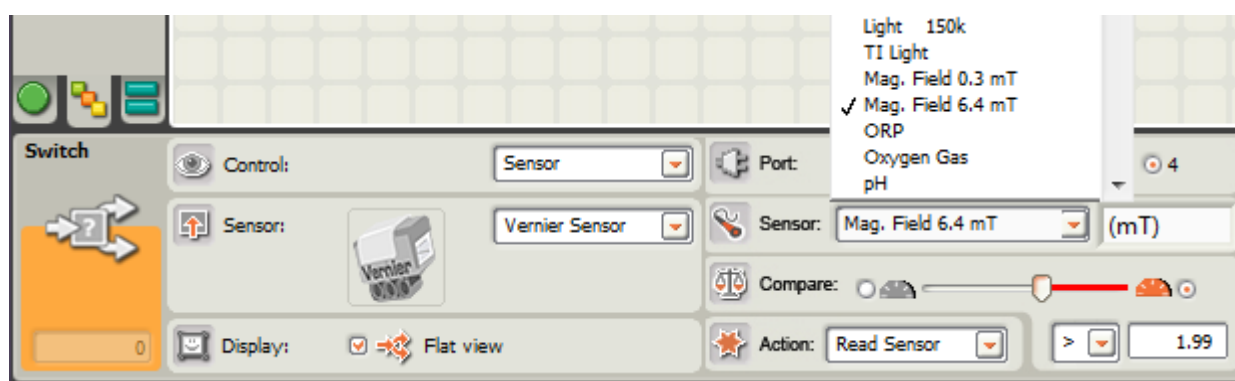


Solar Panel Holder



If You Are Using the NXT Brick

You can perform all the activities listed in this booklet with LEGO's NXT Brick and Mindstorms software. While the programming blocks in the NXT software have a different appearance than the EV3 blocks, they work essentially the same. To configure a Switch block for any Vernier sensor, you select Vernier Sensor from the Sensor pop-up list on the left, and then select the particular type of sensor (such as Mag Field 6.4 mT) from the Sensor pop-up list on the right as shown in the figure below. Be sure the Port number matches the port in which you plugged the sensor. Comparison Types and Threshold Values are set in the lower right corner of the configuration window.

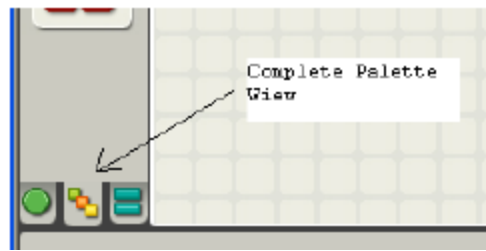


NXT configuration window for a Switch block

Included below are a set of sample programs for each activity written with NXT software. Be sure to import the Vernier Sensor Block (available as a free download from the Vernier website www.vernier.com) into the Mindstorms software before programming.

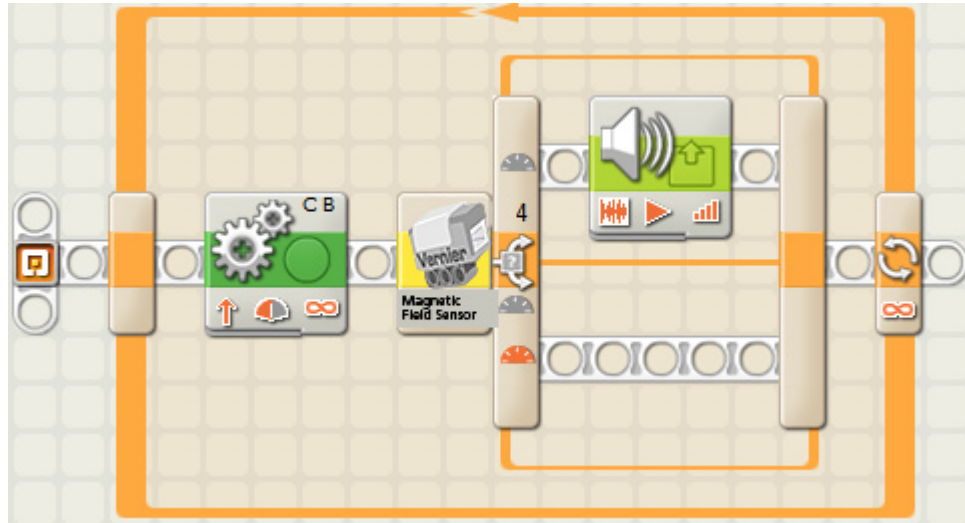
Importing the NXT Vernier Sensor Block V2.0

1. Start NXT V2.0 Programming.
2. Choose Tools » Block Import and Export Wizard.
3. Choose Browse and navigate to the Vernier Sensor Block folder. (Note: It may be in the Download section on your computer.)
4. Select Vernier Sensor and click OK.
5. After a few seconds, the words "Vernier Sensor" should appear as the name of the block to import.
6. Click on the name "Vernier Sensor" and then change the Palette from Advanced to Sensor.
7. Click on Import.
8. In a few seconds the Vernier Sensor block should be imported into your copy of NXT V2.0 Programming. Be sure to choose the Complete Palette View to access the Vernier Sensor Block.

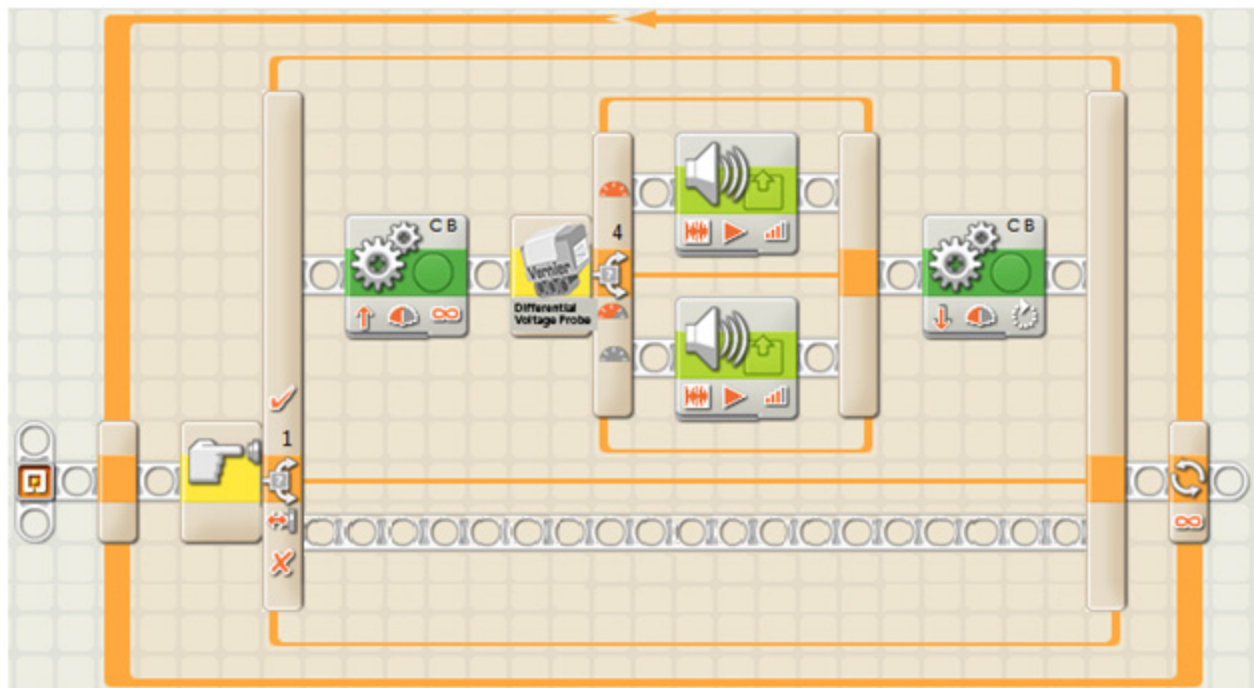


NXT Complete Palette View button

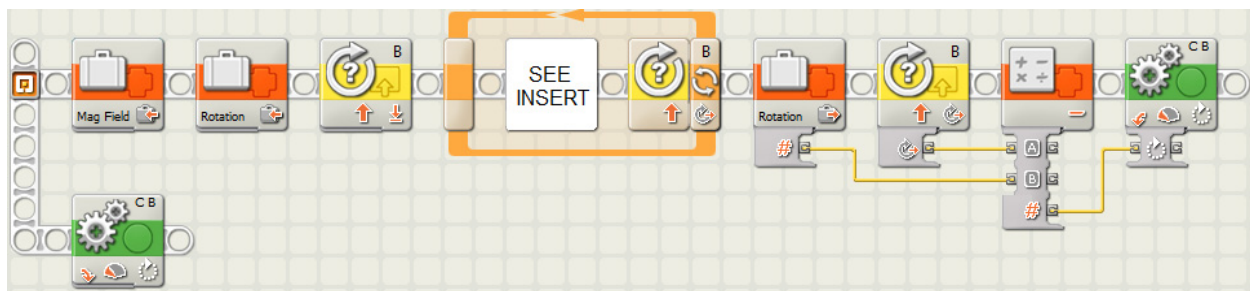
NXT Sample Programs



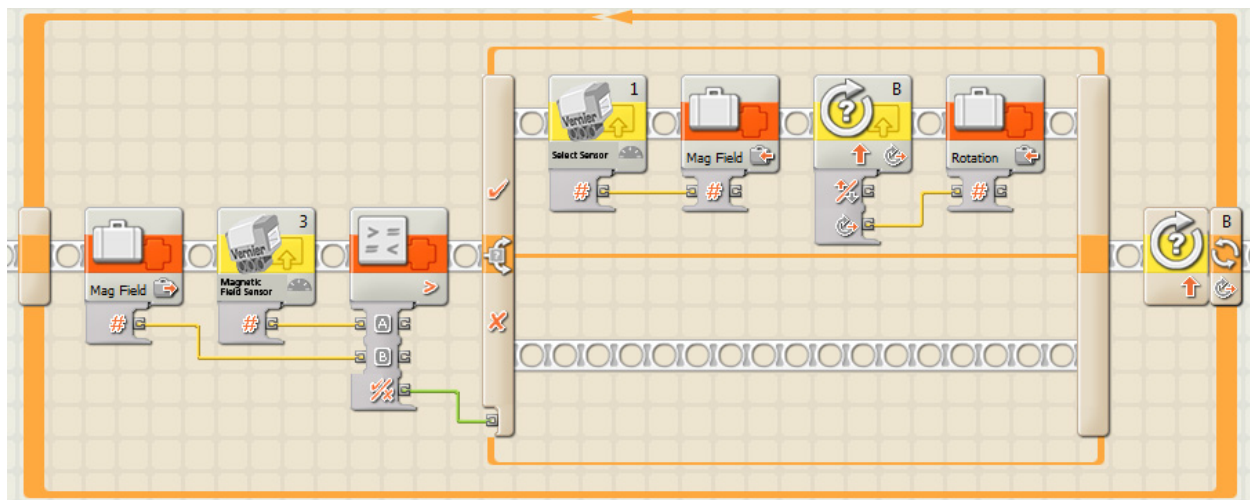
NXT program for a Magnet Detector



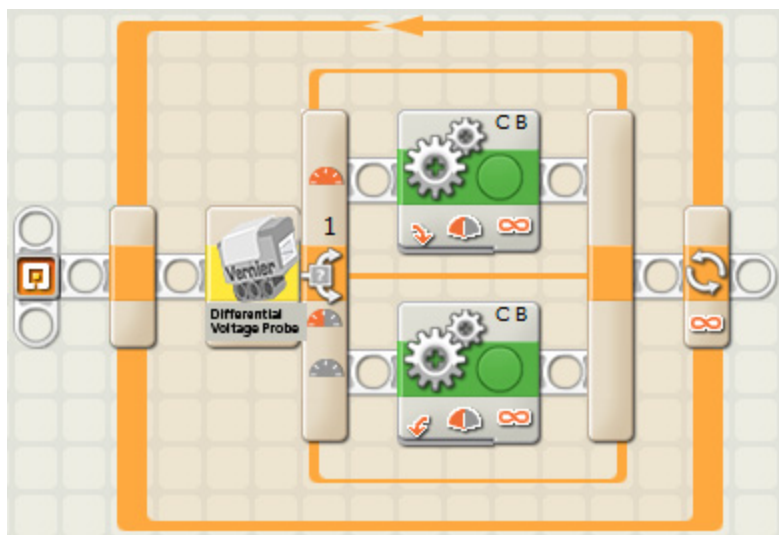
NXT program for a Battery Tester



NXT program for a Compass



Detail for NXT Compass program



NXT program for a Solar Tracker

Safety

When working with motorized equipment, some rules are necessary to prevent accidents and ensure a safe working environment. The following rules are offered as a guideline to your students for proper behavior while working with robots and computers. Feel free to modify them to suit your particular situation.

- Conduct yourself in a responsible manner at all times.
- Follow all verbal and written instructions given by the teacher.
- Ask questions if you do not understand.
- Work in the classroom only when the instructor is present.
- Wear safety goggles when instructed. As a minimum, safety goggles should be worn when working with chemicals or flying objects.
- Report all accidents, no matter how trivial, to the instructor immediately.
- Dress properly to ensure baggy clothing, dangling jewelry, and long hair do not get caught in rotating motors. Long hair should be tied back or tucked into a shirt collar.
- Do not handle classroom equipment that is not a part of your project without permission from the teacher.
- Respect your teammates.

Use caution when working with neodymium magnets; they are incredibly strong. Two magnets snapping together at the wrong angle can pinch your fingers. To help prevent this from happening, glue each magnet to the underside of a LEGO brick. This has the added benefit of making the tiny disk magnets easier to find when they are scattered on the floor.

Standards

- Science as Inquiry – 1: Abilities necessary to do scientific inquiry
- Understand the total energy in the universe is constant
- Understand concepts and processes of evidence, models, and explanations
- Apply knowledge and skills of science and technology to design solutions to human problems

Content Standards

- Use appropriate laboratory apparatuses, technology, and techniques safely and accurately when conducting a scientific investigation. Ba.2, Ca.2, ESa.2, Ma.2, Pa.2, PAa.2
- Use scientific instruments to record measurement data in appropriate metric units that reflect the precision and accuracy of each particular instrument. Ba.3, Ca.3, ESa3, Ma.3, Pa.3, PAa.3
- Organize and interpret the data from a controlled scientific investigation by using mathematics, graphs, models, and/or technology. Ba.5, Ma.5
- Create and interpret tables and graphs to draw conclusions and make predictions. 6.M.2f

NGSS Standards

- Ask questions about data to determine factors that affect the strength of electric and magnetic forces. MS-PS2-3.
- Conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact. MS-PS2-5.

NSTA Standards

- Students should develop general abilities, such as systematic observations, making accurate measurements, and identifying and controlling variables. They should also develop the ability to clarify their ideas that are influencing and guiding the inquiry, and to understand how those ideas compare with current scientific knowledge. Students can learn to formulate questions, design investigations, execute investigations, interpret data, use evidence to generate explanations, propose alternative explanations, and critique explanations and procedures. A.1.2.a
- Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations. A.2.4
- Scientific investigations result in new ideas and phenomena for study, generate new methods or procedures for an investigation, or develop new technologies to improve the collection of data. All of these results can lead to new investigations. A.2.7
- Science and technology are reciprocal. Science helps drive technology, as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and technique. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance,

location, size, and speed. Technology also provides tools for investigations, inquiry, and analysis. E.2.3

- Designing and conducting a scientific investigation requires introduction to the major concepts in the area being investigated, proper equipment, safe precautions, assistance with methodological problems, recommendations for use of technologies, clarification of ideas that guide the inquiry, and scientific knowledge obtained from sources other than the actual investigation. The investigation may also require student clarification of the questions, method controls, and variables; student organization and display of data; student revision of methods and explanations; and a public presentation of the results with a critical response from peers. Regardless of the scientific investigation performed, students must use evidence, apply logic, and construct an argument for their proposed explanations. A.1.2.a
- A variety of technologies, such as hand tools, measuring instruments, and calculators, should be an integral component of scientific investigations. The use of computers for the collection, analysis, and display of data is also a part of this standard. Mathematics plays an essential role in all aspects of an inquiry. For example, measurement is used for posing questions, formulas are used for developing explanations, and charts and graphs are used for communicating results. A.1.3.a

Facts about Mars

On August 5, 2012 NASA's *Curiosity* rover landed on Mars. Its primary mission was to search for evidence of past life embedded in the rocky plains. Electricity and magnetism were critical components to the success of this mission, because without them the rover could not power its instruments, communicate with scientists on Earth, locate potential drilling sites, or maintain balance while traveling over the surface. But how is magnetism used to search for past life?

Martian rocks contain magnetite – a naturally occurring magnetic mineral found in nearly all igneous and metamorphic rocks. However, magnetite is also found in small quantities in terrestrial bacteria on Earth. These bacteria can breathe without oxygen, prefer living in the dark, and love to eat iron. As the bacteria digest the iron, they form magnetite. Mars is known for having an abundance of iron in its soil and recent missions have discovered rich layers of magnetite. It is *Curiosity*'s task to determine whether the magnetite is just another mineral or was formed by ancient bacteria.

Magnetite and iron can be found in the cellular structures of many creatures on Earth. Honeybees, pigeons, tuna, dolphins, and whales rely on the magnetite found in their brain cells to migrate and give them a natural sense of direction. Chitons, a type of mollusk, use magnetite crystals on their radula to scrape food from rocks. Humans use iron to produce red blood cells and transport oxygen throughout the body. Without sufficient iron, people could potentially bleed to death if they cut themselves. Scientists believe that an abundance of magnetite and iron on Mars is a strong indicator that Mars could once have supported life.

When *Curiosity* finds a rock containing magnetite, it drills into the rock and sends a sample to SAM – the *Sample Analysis at Mars* laboratory built right into the robot. SAM heats the rock sample and then uses a gas chromatograph to determine whether the sample contains organic carbon. Carbon provides the backbone element for creating the majority of molecules in all biological systems. SAM can also tell if the sample contains oxygen, hydrogen, and nitrogen—elements that are associated with life as we know it.

Curiosity is currently sampling the rocks on Mars in Yellowknife Bay, a clay-rich lakebed in the center of Gale Crater. Since clay minerals form in the presence of water, Yellowknife Bay is a good place for *Curiosity* to look for evidence of past life. Clay is also a well-known material for preserving organic elements from the high levels of solar radiation on Mars. The abundance of magnetite in Yellowknife Bay suggests the rocks were turned into clay after they were washed downstream. *Curiosity* has also found smectite, a clay mineral found in biologically-rich lake deposits on Earth. *Smectite* is that sticky clay that sticks to your shoe when you step too close to the edge of a river or lake.

Some people wonder why we are sending robots to Mars before humans. Robots have fewer needs and can endure hostile conditions. Robots do not need food, water, or oxygen, things that humans cannot live without. While robots cannot think for themselves, they can be programmed to perform many tasks. Robots are like scouts who are exploring the surface and paving the way for future astronauts. Just as the early settlers followed Lewis and Clark across the Continental Divide to the Pacific Ocean, one day humans will join robots on our exploration of Mars.

Career Overview: Aerospace Engineers

Aerospace engineers design, develop, test, and supervise the manufacture of any type of flight vehicle, including planes, helicopters, space stations, rockets, satellites, missiles, and planetary rovers. Those who specialize in aircraft that operate within the Earth's atmosphere are called *aeronautical* engineers, while those who design spacecraft that travel beyond the Earth's atmosphere are called *astronautical* engineers.

Aerospace engineers develop new technologies using CAD software, robotics, and advanced electronics. The design of a flight vehicle is a process involving many complex physical principles, including structural strength, aerodynamics, propulsion, guidance, navigation, control, communication, instrumentation, thermodynamics, materials, and production. Unlike ground-based vehicles (cars, trains, buses, etc), flight vehicles must withstand extreme changes in atmospheric pressure, temperature, and gravitational acceleration.

The aerospace industry is a growing field employing thousands of engineers. Some companies, like Boeing and Lockheed Martin, build commercial airplanes and military fighter jets, while other companies, like Southwest Airlines and Federal Express, use airplanes to transport people and materials. NASA was once the sole source for all US space missions, but private companies, like Virgin Galactic, are moving into commercial space flights. The skills used by aerospace engineers are not restricted to aircraft, however. Many aerospace engineers are hired by automobile manufacturers to improve the aerodynamics of cars and trucks. Sporting goods manufacturers employ aerospace engineers to design balls that fly faster and higher. The medical industry hires aerospace engineers to analyze the fluid flow around artificial heart valves.

The future of aerospace is exciting and challenging. Within your lifetime, you are likely to see space-based solar power stations, commercial flights to the Moon, and human explorers on Mars. If you like the idea of designing and testing things that fly, then aerospace engineering is for you.

Links of Interest

- *Happy Anniversary, Curiosity!* American Museum of Natural History, August 2013. www.amnh.org/explore/news-blogs/news-posts/happy-anniversary-curiosity?gclid=COKG2vbj2rsCFew7MgoddTEAoQ
- *How Batteries Work.* How Stuff Works, 2014. electronics.howstuffworks.com/everyday-tech/battery6.htm
- *How Compasses Work.* How Stuff Works, 2014. adventure.howstuffworks.com/outdoor-activities/hiking/compass.htm
- *How Solar Cells Work.* How Stuff Works, 2014. science.howstuffworks.com/environmental/energy/solar-cell.htm
- *Magnetic Math.* NASA Goddard Space Flight Center, August 2009. www.nasa.gov/pdf/417438main_Magnetic_Math.pdf
- *Magnetic Rocks May Reveal Martian Life.* Davison, Anna. New Scientist, May 2008. www.newscientist.com/article/dn13863-magnetic-rocks-may-reveal-martian-life.html#.Uq4rIHmA3IU
- *Mars' Magnetic Field.* National Space Institute, April 2014. www.space.dtu.dk/english/Research/Universe_and_Solar_System/magnetic_field
- *Mars Math Educator Guide.* NASA Education, May 2013. www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Mars_Math.html
- *NASA Explores the Red Planet.* NASA, June 2014. www.nasa.gov/mission_pages/mars/main/index.html
- *NASA Rover Results Include First Age Measurement on Mars and Help for Human Exploration.* NASA News, December 2013. www.nasa.gov/jpl/msl/mars-rover-curiosity-20131209.html
- *Solar Array Design: Parallel Wiring Opens New Doors.* Renewable Energy World, July 2014. www.renewableenergyworld.com/rea/news/article/2010/08/solar-array-design-parallel-wiring-opens-new-doors
- *Solar Kit Lessons.* National Renewable Energy Laboratory, 2014. www.nrel.gov/education/pdfs/nesea_solar_kit_lessons.pdf
- *Structure and Properties of Matter.* Next Generation Science Standards, 2014. www.nextgenscience.org/msps-spm-structure-properties-matter
- *What's My Mission? Launching Curiosity to Mars.* NASA Jet Propulsion Laboratory, 2014. mars.jpl.nasa.gov/msl/multimedia/slideshow/index-2.html
- *Wired for Space.* NASA Connect, January, 2001. archive.org/details/NasaConnect-WiredForSpace

Engineering Notebook

The following eight pages comprise the Engineering Notebook. This gives your students a nice place to record the observations and sensor measurements they make during their investigation of electricity and magnetism. If you photocopy the pages in order back-to-back as two-sided copies, fold in the middle and staple, you will have a small booklet to hand out to your students. Be sure each student gets his or her own copy.

Throughout this unit, your students will be implementing the engineering design method as they work toward building a successful working robot capable of completing each of the tasks in the Martian Challenge. Reinforce the importance of each step to your students as they tackle each new activity. Be sure to allow ample time for testing and revisions.

Steps in the Engineering Design Method

- Identify design objective
- Define goals and identify limitations
- Research
- Brainstorm potential solutions
- Analyze viability of solutions
- Choose appropriate solution
- Build
- Test and evaluate
- Revise and repeat