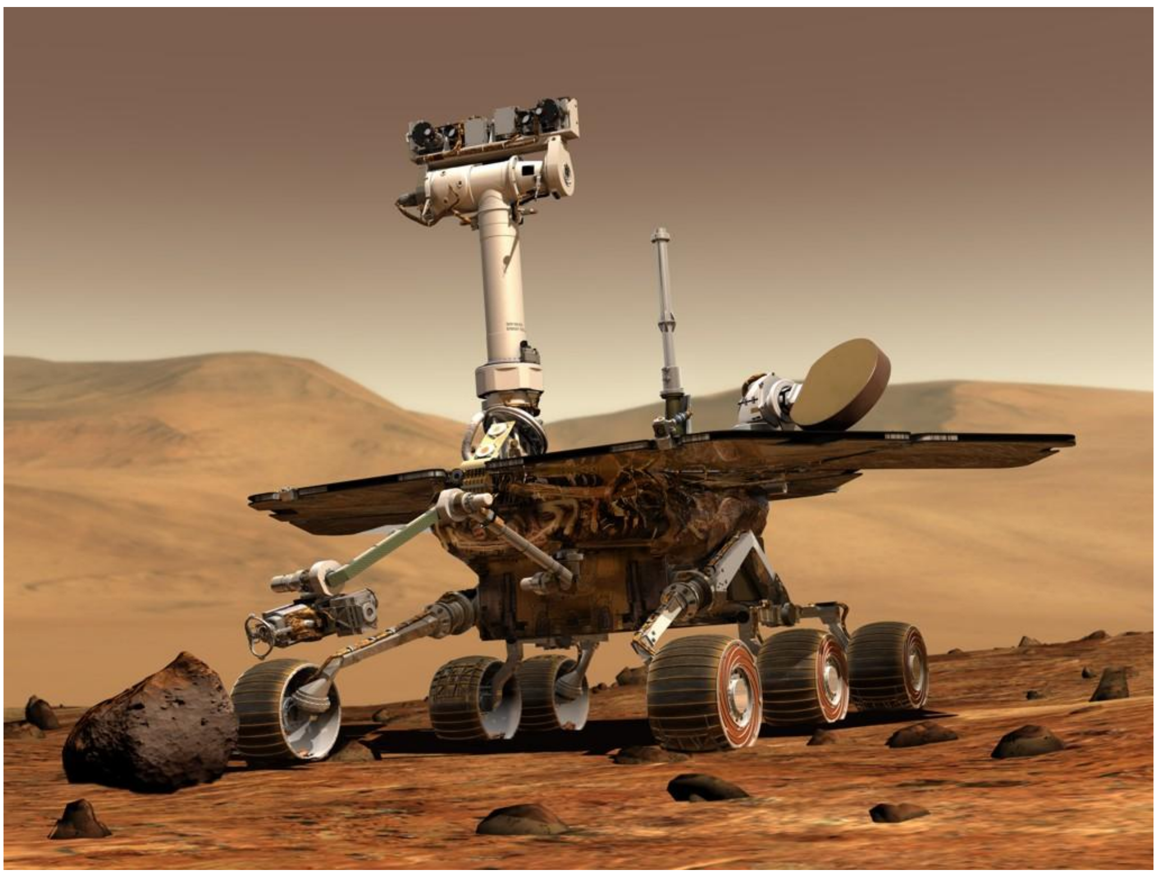
ASTRONOMY ACTIVITIES

USING LEGO ROBOTICS



Questions? Comments?
info@technicallylearning.org

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ACTIVITIES

1. INTRO TO MARS ROVER: DESCENDING INTO A CRATER

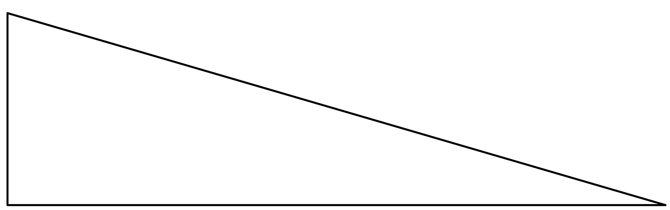
Goal: To win a competition by having your un-powered rover roll the farthest after coasting down the side of a Mars crater

Main Themes:
- Gravity as a means of propulsion
- Investigating the LEGO kit
- Building familiarity and confidence with construction

Theory: Gravity pulls the rover into the crater, and it gains speed as it rolls down. Then it rolls as far as it can into the crater, until friction eventually stops it.

Pre-Activity Preparation: Build a gentle-incline ramp. Cardboard pieces taped together work well. The ramp only needs to be 6 or 8 inches tall to make this work. Make the ramp shorter if you don't have much room for the rovers to roll.

Ramp:



Construction Tips:
- Make sure that the students build a vehicle of some sort. While a single wheel rolled down the ramp could win, in theory, that won't help them develop building skills.
- The NXT is not required since there is no need to power the rover. The extra weight won't make the rover roll more or less, even if you add it.

Discussion Questions:
- Do the rovers roll further when released higher up the ramp? Why?
  - Yes. The rover has longer on the ramp to gain more speed. Put in another way, gravity has more distance to pull the rover down.
- How would your rover be affected by the weaker gravity on Mars?
  - Since the gravity on Mars is weaker than on Earth, the rover builds up less speed and would travel slower on Mars.
- How would your rover be affected if it were on different surfaces, such as the dust and sand on Mars?
  - The loose dust and sand causes more friction, which slows the rover down more than a smooth hard surface.
- Was there a certain type of rover that went further than others? Any noticeable patterns?
  - There may be no pattern. Patterns may only emerge after each rover has been run 5 or so times, and the distances are averaged.
- Next, have them do 5 runs down the ramp and record the distance their rover travels for each.
  - Why are the distances different from run to run for the same rover?

        - Many factors that affect the distance can change slightly from run to run: air currents, how it is released, dust bunnies, etc.
    - Average the distance for each rover across the 5 runs. Compare the rovers' average distances. Are there any patterns for what types of rovers go the furthest?
        - Rovers with bigger wheels tend to go a little further
        - The weight of the rover doesn't influence the distance

Activity Variations (optional):

- Let the rover roll down the ramp 5 times with rubber treads on your wheels. Then do 5 runs with no rubber on the wheels (just the hard plastic hub). Record the distance that the rover travels for each run. Average the distances for the rubber wheels and the non-rubber wheels.
    - Which type of wheel rolls further? Why?
        - The wheels without rubber should roll slightly further. The rubber wheels produce slightly more friction because the rubber slightly deforms at the point touching the ground. This extra friction causes the rubber wheeled rover to slow down and stop sooner than the non-rubber wheeled rover.
- This activity could be repeated on different surfaces, such as on top of cardboard, on carpet, linoleum, or pavement outside.

Additional Mars Rover Resources:

http://marsrovers.jpl.nasa.gov/gallery/video/challenges.html
Video Title: *Testing the Rovers for the Treacherous Martian Terrain* (third item on the page)
This video shows NASA engineers determining the limits of the rovers. They build a ramp, and see how steep of an incline the rovers can ride over.

2. REMOTE CONTROLLED ROVER

Goal: Understand why the Mars rovers need to be autonomous, rather than operated by remote control.
Build a rover with motors that are controlled by 2 touch sensors. The students will use the touch sensors to drive the rover first without a delay, as if it is directly remote controlled. Then the students will use the provided program to try driving the rover with a delay between command and response. The students will discover that this makes the rover very difficult to navigate.

Main Themes:

- Rover construction with touch sensors
- Gaining familiarity with different Lego parts
- Distance between Mars and Earth

Robotics Theory: Sensors can be used to give input to the rover's computer, and the program can tell the rover to respond to that input in a particular way. This is similar to how humans use their senses and respond to their environment.

Astronomy Theory: A signal takes several minutes to reach Mars from Earth because of the great distance between planets. By the time a command reaches the rover, it might be too late for the rover to respond correctly. Therefore, the rover must be able to navigate on its own.

Construction Tips:

- The students should follow the instructions in the book that came with the LEGO kits, starting on page 8. This will lead them through constructing a rover.
- The left motor should be connected to **port B** and the right motor should be connected to **port C**
- Then take the 2 touch sensors, and connect one to port 1 and the other touch sensor to **port 2**.
- Hold the touch sensor from port 1 in your left hand and the port 2 touch sensor in your right hand. Walk along with the rover as it drives forward. Pressing the right sensor will make the rover turn right, and pressing the left sensor will make the rover turn left.

Sample Code:

- First, use the provided program without the delay to practice driving the remote controlled rover.
- Then, use the provided program *with* the built in delay. This simulates controlling a rover from a greater distance.

Discussion Questions:

- Was it harder to control the rover with or without the delay? Why?
- Now imagine the delay to control the rover is 5 minutes or more. Why wouldn't this work for NASA scientists and their Mars rover?
    - The scientists would have to send only 1 movement every few minutes, and it would take too long to get anywhere on Mars.

- Also, there would be no way to respond in time to obstacles that were previously unknown.
- Therefore, the rover needs to be able to navigate on its own (autonomous rover).

Picture of Rover with 2 touch sensors connected

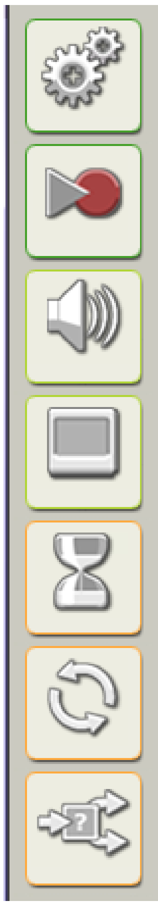
3. TEACHER LED: DEMONSTRATE NXT PROGRAMMING

Goal: Show students the basics of NXT programming

Background: The NXT is the computer for the rover. The NXT also provides power to the motors and sensors.

Programming overview:

- NXT programming uses icons to represent actions your robot can take.



Move - Choose these icons to activate motors

Record/Play - record movements and then replay them

Sound - play sound files or tones

Display - Change the display on your robot (i.e. show an image or text)

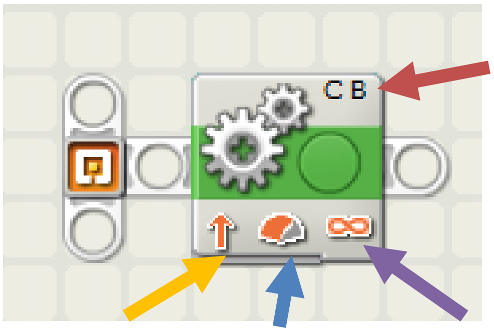
Wait For - Wait for a change in light readings, a distance to an object, or a button push

Loop - use loops to create indefinite behaviors

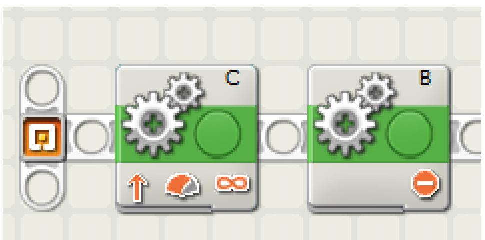
Switch - choose from 2 different actions (i.e. do one action if the touch sensor is pressed in, do a different action if the touch sensor is not pressed)

- Each programming icon you select from the menu panel on the left of the screen has many properties you can edit. These properties are reflected on the icon.

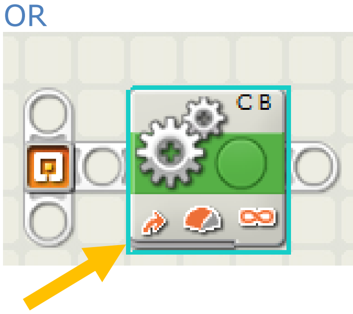
Motors:



- **Port**: On this "Move" icon, the red arrow is pointing at the letters (C,B) which indicate which motors will be turning.
- **Duration**: The purple arrow shows how long the motors will be turning. In this case the "infinity" symbol is shown because the motors are set to turn an unlimited amount.
- **Power**: The blue arrow points to the power level. On this icon, it is shown at about ¾ power.
- **Direction and Steering**: The yellow arrow shows the direction the motors are set to turn. This icon shows that the motors will move forward.



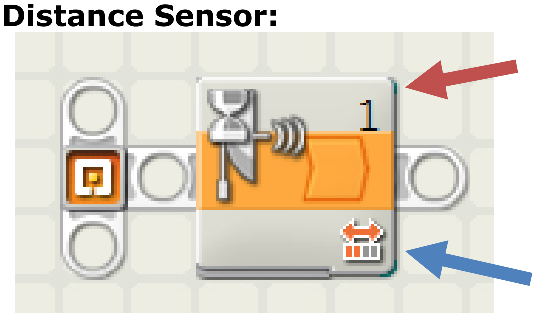
OR



There are 2 ways to tell the motors to turn the wheels:

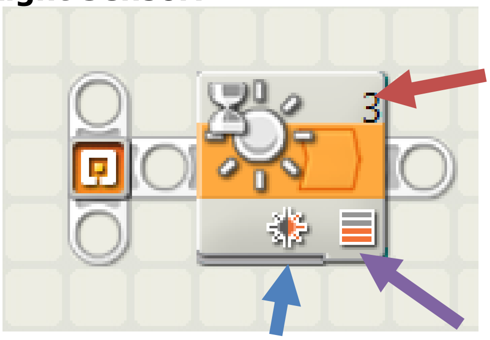
- To tell the rover to turn to the right, the easiest way is to turn on the left motor (C) while telling the right motor (B) to stop. This causes the left wheel to rotate, turning the rover to the right. A slight variation is to turn on the left motor going forward, while the right motor is on going backwards. This causes the rover to rotate to the right in place. This is similar to how some vehicles, such as tanks and wheelchairs, navigate and turn.
- Or you can turn on both motors (C and B) and use the steering slider in the motor properties to tell it to turn right.

Distance Sensor:



- **Port**: On this "Wait for Distance" icon, the red arrow points to the port number that the distance sensor is connected to, in this case, port 1.
- **Wait 'Until'**: The blue arrow points to a visual representation of the distance selected. In this case the slider is show about half full, indicating that it will wait for an object to be about half of the distance that the sensor can detect. This is a value of 50 inches.

Light Sensor:



- **Port:** On this "Wait for Light" icon, the red arrow points to port number for this sensor.
- **Wait 'Until'**: The purple arrow points to a picture of the value of light the NXT will wait for. In this case, it shows the bars about half full, indicating that the robot will be waiting for a light level about halfway between dark and very-bright.
- **Function:** The purple arrow points to a image indicating that the light sensor will generate its own light. (This is useful for reflecting off of nearby surfaces to sense them. See activity 8)

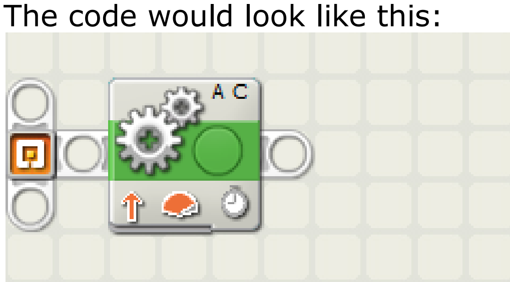
- String the icons together in linked in a chain to form more complex series of behaviors for your robot.
- The NXT will execute each command or action in order.
- When the NXT gets to the end of the program, it is done executing commands, but the motors will stay on unless you explicitly stop them.

Construction Demo:

- Use a wire connector to hook up a motor to one of the NXT outputs (use either the A or C ports on the NXT)
- Attach a wheel to the motor to make the spinning more visible

Sample Code:

- Write a simple program that turns on the motors for 5 seconds.
    - The code would look like this:



- Download this program to the NXT and demonstrate that it causes the motor to turn on and spin the wheel.

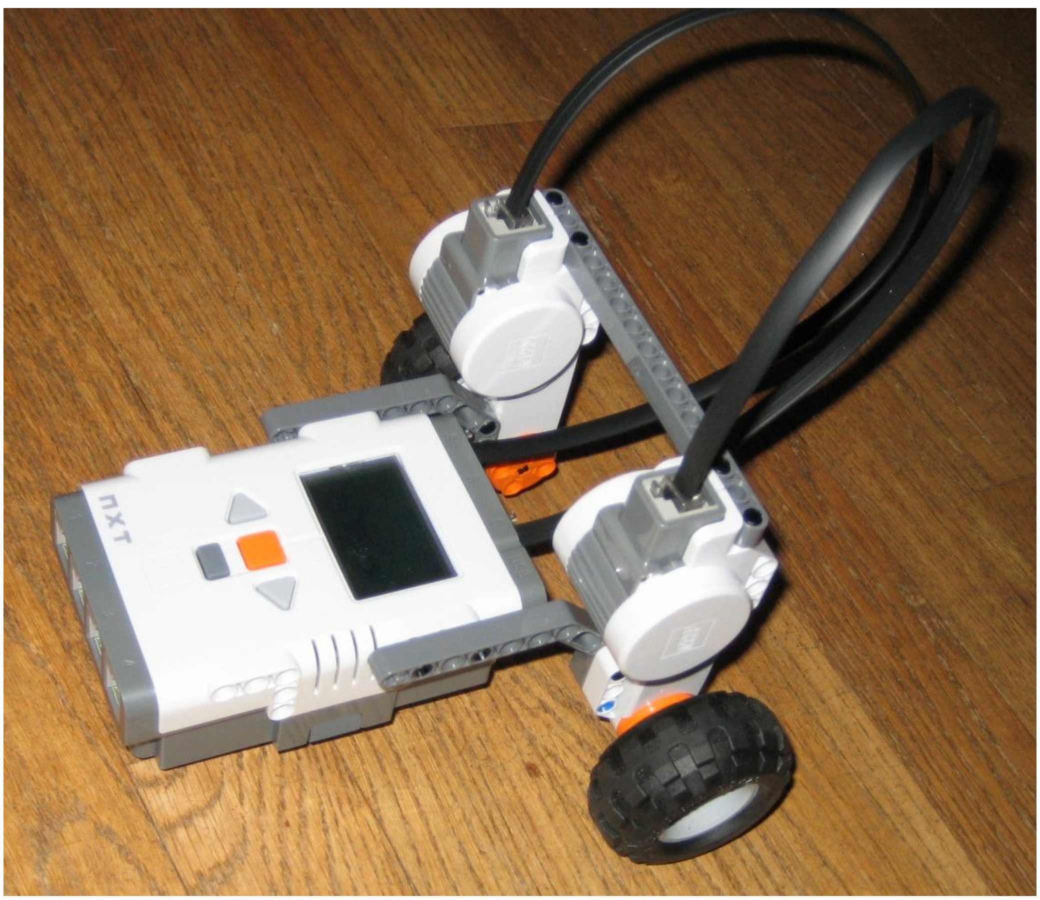
4. DRIVE FORWARD

Goal: Build a motorized rover that drives forward

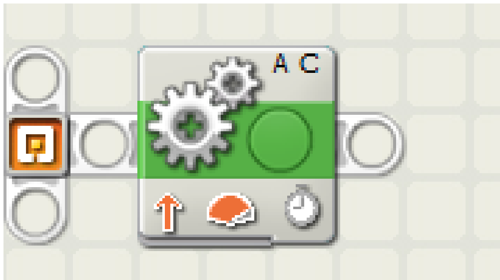
Main Themes:
- Rover construction
- NXT Programming

Robotics Theory: Generally, mobile robots are designed with 2 motors in the back, one for each wheel, and a center un-motorized pivot wheel in the front. This allows the rover to turn easily by having only one motor on, and drive in a straight line by having both motors on. It can also pivot in place by turning on one motor forward and one motor backwards.

Construction Tips:
- The most basic LEGO rover consists of:
  - 2 motors under the back of the NXT, with wires connected to the lettered ports, which provide power output.
  - Reinforce the motors (so they stay on the rover) with LEGO strips connecting both motors
  - Attach wheels to the motors using axles
  - A front wheel is not necessarily needed



Sample Code:



This program tells the rover to:

- Turn on motors A and C in the forward direction for a timed amount (e.g. 3 seconds)

Discussion Questions:

- How would you make your rover go faster? How about slower?
  - Use wheels that are larger in diameter to make the rover go faster.
  - Use wheels that are smaller in diameter to make the rover go slower.
- Did your rover go in the direction you expected? Why or why not? What did you do to correct it?
  - "Forward" is a particular direction for the motors, and turning the motors around will make the rover go in the opposite direction.
  - If the rover was veering off in one direction, check that nothing (i.e. a wire) was blocking a tire from spinning freely.

Activity Variations (optional):

- Make your rover rotate in place

5. AVOID MARTIAN ROCKS

Goal: To build a rover that drives forward until it senses an object.

Main Themes:

- Using the ultrasonic distance sensor to detect when the rover approaches an object

Robotics Theory: Sensors allow the rover to gain information about its surroundings. The program can then make decisions based on this information. The ultrasonic distance sensor uses sound pulses to determine the distance to an object in front of the rover. The sensor measures the amount of time between when it sends out the pulse of sound and it detects the reflected sound pulse. This is the same technique that is used by bats to navigate in the dark. The Mars rover uses similar techniques with light pulses to determine the distance to objects on the surface of Mars.

Construction Tips:

- Make your rover very sturdy by adding lots of reinforcement.
- Attach the distance sensor firmly to the rover, connecting it to a numbered input port
    - Make sure that the distance sensor is pointing in the forward direction.

Sample Code:

This program tells the rover to:

- Turn on motors C and B in the forward direction for an unlimited duration. They will stay on until another command tells them to turn off.
- Wait until the distance sensor detects an object less than 10 inches away (use the slider on the properties panel to change the default 50 inches to 10 inches)
- Then stop both C and B motors

Discussion Questions:

- Are there any objects that your rover couldn't detect?
    - Could it detect glass?
        - Yes, the sound pulses would reflect from the glass
    - Could it detect a pencil laying on the ground?
        - No, the pencil is too small to be detected by this sensor
- Would this rover be able to drive around Mars?
    - This rover wouldn't be about to detect small rocks and obstacles, and would probably have a hard time navigating the landscape. The real Mars rover uses multiple techniques to detect objects, including cameras, lasers, and probes.

Additional Mars Rover Resources:

http://marsrovers.jpl.nasa.gov/gallery/video/hardware.html
Video Title: *Rover First Steps* (located near the bottom of the page)
NASA engineers had to figure out what size rock is too big to roll over. They did this through extensive testing on Earth. The real rovers are able to drive over very difficult terrain.

6. EXPLORE MARS

Goal: To build a rover that roams around indefinitely, avoiding obstacles by turning away from them.

Main Themes:

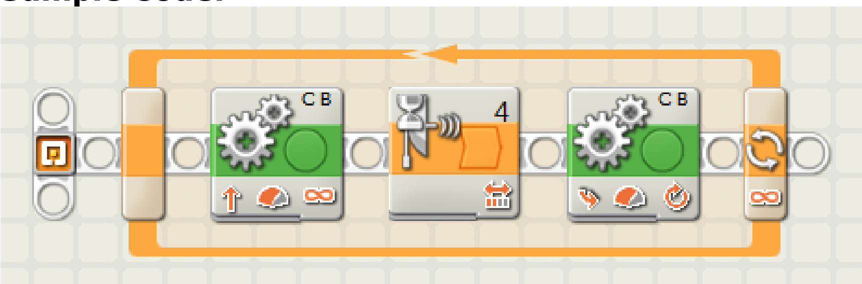
- Programming with loops to create infinite behaviors

Programming Theory: Loops are used in programming to create behaviors that repeat infinitely or for a specified number of times.

Construction Tips:

- Same rover as activity 5

Sample Code:



This program tells the rover to:

- Turn on motors C and B in the forward direction for an unlimited duration. They will stay on until another command tells them to turn off.
- Wait until the distance sensor detects an object less than 10 inches away (use the slider on the properties panel to change the default 50 inches to 10 inches)
- Then change the C and B motors in the following ways:
    - Go in the backwards direction
    - Use the steering slider to make it turn while go backwards
    - For a short duration (e.g. 5 rotations or 2 seconds)
- Loops back to the beginning of the program, to repeat these commands infinitely.

Discussion Questions:

- How long will this rover keep roaming?
    - This program will keep looping infinitely. So, the rover will roam until it runs out of batteries, you stop it, or it breaks apart from hitting obstacles that the sensor misses.
- Did your rover eventually fall apart? What can you do to make it stronger?
    - Reinforce all of the pieces connected to the NXT

Additional Mars Rover Resources:

http://marsrovers.jpl.nasa.gov/gallery/video/spirit01.html
Video Title: *Spirit on Mars* (located about half way down the page)
This video shows the path of Spirit from its hazard-avoidance camera during the first 343 Martian days.

7. POWER DOWN AT NIGHT

Goal: To build a rover with a light sensor that drives forward, stops when the lights in the room go off, and starts driving again when the lights come back on.

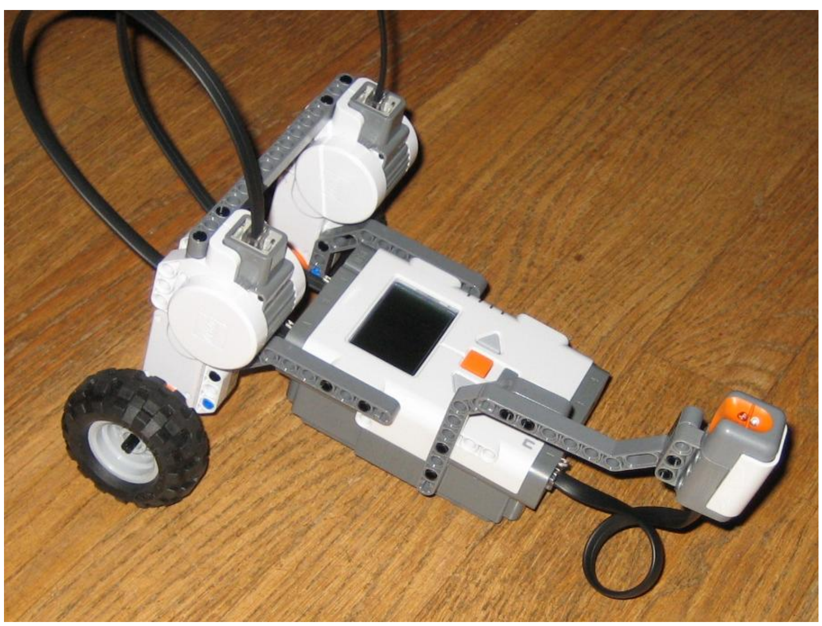
Main Themes:

- Using the light sensor to monitor ambient light
- Programming a sequence of multiple behaviors

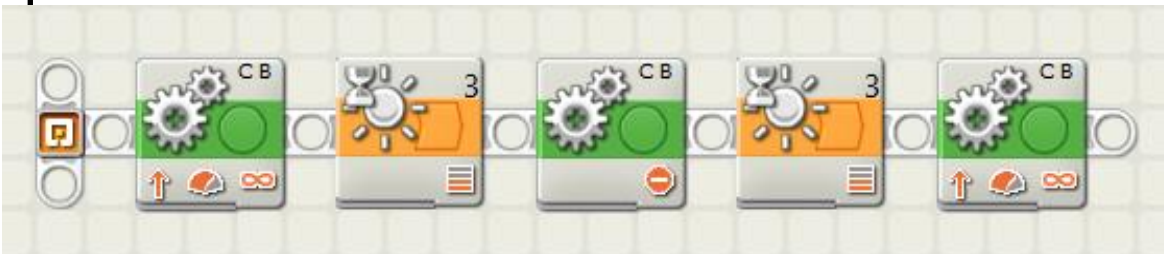
Astronomy Theory:
The only power the Mars rovers have comes from their solar panels (small solar panels are commonly used in pocket calculators). Therefore, they are only collecting power during the day. Some systems, such as heaters to keep the motors and electronics from freezing, must remain on all the time. If the rovers use energy by moving around at night, they risk running out of battery power. If this happens, the systems that are supposed to remain on all the time will shut off, risking major damage to the rover. It is therefore necessary to stop motion during the Martian night. Also, NASA engineers let the rovers 'hibernate' during Martian winters; due to the low amount of sunlight, the rovers wouldn't be able to move. Interestingly, dust devils occasionally hit the rovers, clearing off the dust and increasing the efficiency of the solar panels.

Construction Tips:

- Point light sensor towards the ceiling (or towards the lights) to help detect when the room lights go off
- If the room is really sunny, you may need to pull the shades down to get this to work



Sample Code:



This program tells the rover to:

- Turn on motors C and B in the forward direction for an unlimited duration.
- Wait until the light sensor detects less ambient light in the room (classroom lights are turned off). Change the sensor to wait until a darker light value ('<' symbol).
- Then stop both C and B motors
- Wait until the light sensor detects more ambient light in the room (classroom lights are turned back on). Change the sensor to wait until a brighter light value ('>' symbol).
- Then turn on motors C and B in the forward direction

Discussion Questions:

- Did it matter which direction your light sensor faced?
    - Facing down at the ground probably won't work, as the light sensor's red light is reflected off the ground. Facing the light sensor up will work best. The light sensor facing forward, left, or right may work intermittently

Activity Variations (optional):

- Add a loop to your program so the rover drives forward whenever lights are on (the sun is up) and the rover turns off whenever lights go out (night on Mars).

Additional Mars Rover Resources:

http://marsrovers.nasa.gov/gallery/press/spirit/20050819a.html

This press release shows movies of dust devils moving across the surface of Mars. These devils occasionally hit the rover, blowing away the dust that settles on the solar panels. The rovers were expected to stop moving after only a few months, because they would not get any power once the dust settled on the panels. The cleaning from the dust devils has allowed the rovers to operate many years longer than expected.

Additional information can be found in the following:

http://www.newscientist.com/article.ns?id=dn7140

http://marsrovers.jpl.nasa.gov/gallery/video/opportunity01.html

Video Title: *Mars Rovers Battle Severe Dust Storm* (first item on the page)

8. DON'T FALL IN THE CRATERS

Goal: To build a rover that drives around a plateau, detecting when it nears the edge of a crater or cliff to avoid falling off.

Main Themes:

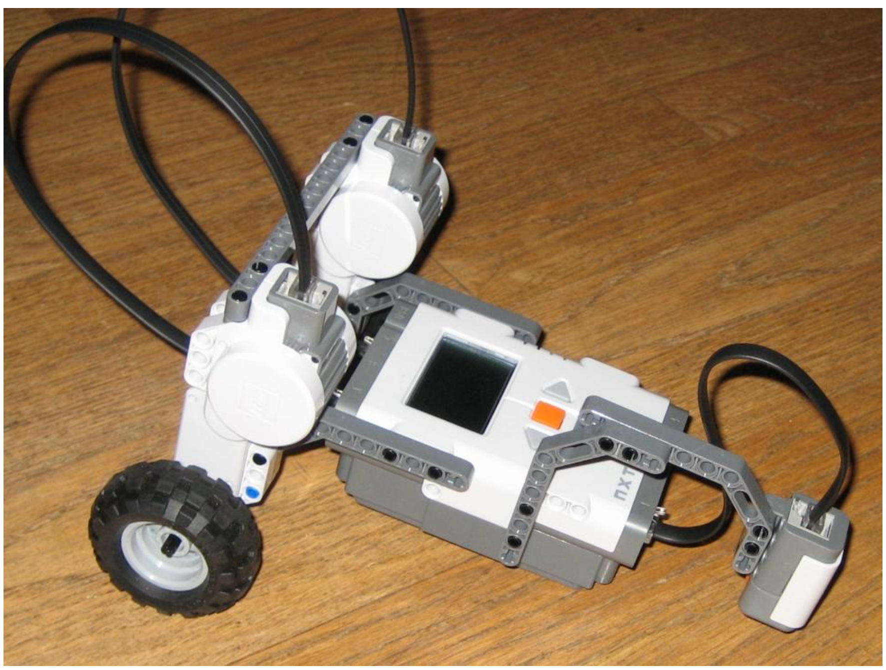
- Using the light sensor to detect the edge of the crater
- Programming with loops to create infinite behaviors

Robotics Theory:

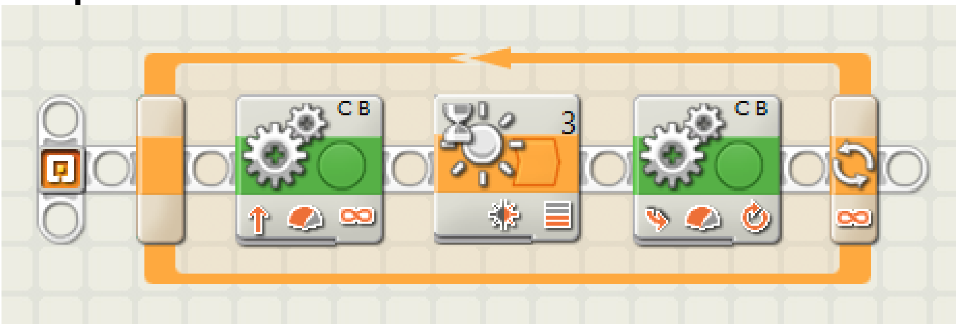
A light sensor pointed down at the ground will monitor that the ground exists below your rover and let the rover know when the edge of the table has been reached. The light sensor contains a red light that reflects off near surfaces (the nearby table). The clear bulb in the light sensor picks up this reflected red light and reads a bright (high) light value. When out over the edge of the table, the light sensor will read a darker value because no light is reflected.

Construction Tips:

- Light sensor should be out in front of the rover
- Light sensor should be pointing down



Sample Code:



This program tells the rover to:

- Turn on motors C and B in the forward direction for an unlimited duration.
- Wait until the light sensor detects less light reflecting back from the table (i.e. when it is hanging over the edge of the table). Change the sensor to wait until a darker light value ('<' symbol).
- Then change the C and B motors in the following ways:
  - Go in the backwards direction
  - Use the steering slider to make it turn while go backwards
  - For a short duration (e.g. 5 rotations or 2 seconds)
- Loop back to the beginning of the program

Discussion Questions:

- What determines how far out in front the light sensor needs to be from the rover?
  - In the time it takes for the light sensor to react, faster rovers will travel a greater distance. So, the light sensor needs to be further out on faster rovers.
- Could you accomplish this same goal using a distance sensor?
  - Yes, build the rover so that the distance sensor is pointed down. The distance sensor measures a greater distance to the next object when it is over the edge of the table.
- Did you rover ever fall off the table? Why?
  - Falls off edge while turning
  - Bad light sensor reading, so the rover kept driving off the edge
  - Rover is too fast or the light sensor is too close to the rover.
- How could you increase the chance that the rover will stay on the table?
  - Slow it down
  - Add a second light sensor (one on each of the front corners of the rover)
- How long will this rover keep roaming?
  - This program will keep looping infinitely. So, the rover will roam forever, or until it falls off the table.

Activity Variations (optional):

- Build a rover that uses an ultrasonic distance sensor to stay on the table.

9. CRATER RIM EXPLORATION

Goal: To build a rover that drives along, following the edge of a crater (a guideline made out of black electrical tape).

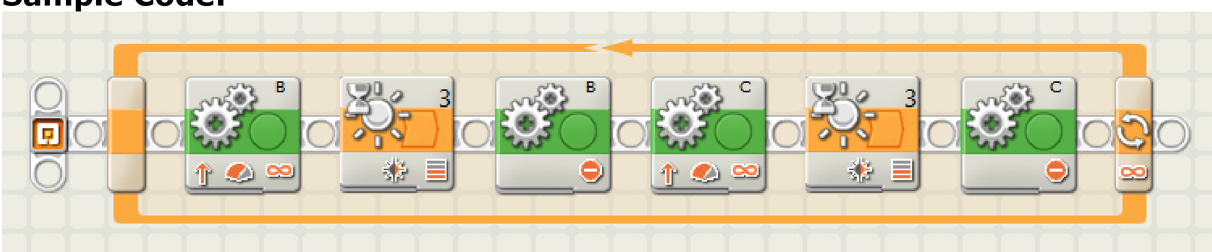
Main Themes:
- Using the light sensor to detect the edge of the crater
- Programming with loops to repeat the rover's behavior infinitely

Robotics Theory: The rover starts with its light sensor on one side of the tape and drives towards the tape until it has crossed the near edge. The rover detects that it has crossed onto the tape when the light sensor picks up a darker value. When it detects that it has driven across the edge of the tape (either onto or off of), it changes directions until it crosses the other way. The rover drives in this zigzag pattern along the edge of the tape.

Pre-Activity Preparation:
- Put tape down on the table or floor in a crater-round shape with some gentle curves. You can also use paper if you don't have tape.
- It is best to use black electrical tape on a light colored floor. (or white paper on a dark floor)

Construction Tips:
- Point the light sensor down in front of the rover, placing it close to the rover.

Sample Code:



Assumption for this code sample: the rover starts with the light sensor over the table or floor, with the darker tape to the left of it. Other configurations will work, but the students will need to know what it is before programming.

This program tells the rover to:
- Turn on motor B in the forward direction for an unlimited duration.
  - This turns the rover to the left, causing the light sensor to swing towards the dark tape
  - Don't go too fast – use the power slider to slow the rover down a little. This will make for more consistent edge following.
- Wait until the light sensor detects less light reflecting back (i.e. when it is over the dark tape). Change the sensor to wait until a darker light value ('<' symbol).
- Stop motor B
- Turn on motor C in the forward direction for an unlimited duration.
  - This turns the rover to the right, causing the light sensor to swing away from the tape, towards the lighter table/floor

- Wait until the light sensor detects more light reflecting back (i.e. when it is over the lighter table/floor). Change the sensor to wait until a brighter light value ('>' symbol).
- Stop motor C
- Loop back to the beginning of the program

Discussion Questions:

- Did your rover ever lose track of the edge of the tape? Why or why not?
    - There are many reasons for inaccurate sensor readings, such as dust, greasy floor, reflection of lights, etc…
    - Tight corners are hard to go around and could cause the rover to lose the edge
- How could you build a rover that is more accurate and less likely to get knocked off course?
    - Use 2 light sensors, one on either front corner of the rover.
    - Slow the rover down so that it has more time to detect changes in the light values (the edge of the tape).

Activity Variations (optional):

- Put down an electrical tape boundary in the shape of a square (4 feet by 4 feet). Make a rover that stays within the square and doesn't cross the tape. (It's very similar code to activity 8)

Additional Mars Rover Resources:

http://marsrovers.jpl.nasa.gov/gallery/video/opportunity01.html
Video Title: *Opportunity Poised to Enter Victoria Crater* (second item on page)
This video shows how Opportunity follows the edge of a crater, looking for a safe path in.

10. FIND WATER ON MARS

Goal:

To build a rover capable of measuring how many deposits of water there are on an unknown Martian landscape.

Build a rover that has a light sensor pointed down at the ground. Write a program that beeps whenever the light sensor picks up a strip of black electrical tape on the ground. Set the rover running over a series of strips in a place the students can't see themselves, and count how many times the rover beeps to determine how many water deposits there are.

Main Themes:

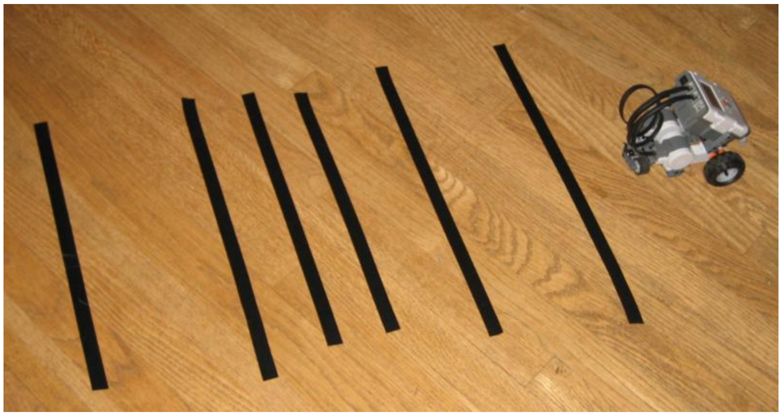
- Using a light sensor for data collection
- Using a robot to measure something humans can't measure themselves

Astronomy Theory:

Although there is currently no liquid water on the surface of Mars, one of the main objectives of sending the rovers to Mars was to see if there was evidence of Mars having liquid water on its surface in the past. The rovers have discovered many pieces of evidence, mostly involving chemistry. Certain types of minerals, such as hematite, only form in the presence of water. Additionally, NASA scientists have found high concentrations of salts. These are thought to have formed when the water they were dissolved in evaporated. The real rovers use sophisticated sensors to determine what materials are present in the rocks on Mars. In this exercise, finding the black tape with the light sensor is like finding hematite or high concentrations of salts using a more sophisticated sensor. The existence of past water on the surface of Mars means that life may have once been possible on Mars. It also suggests that many exo-planets may also be capable of hosting life.

Pre-Activity Preparation:

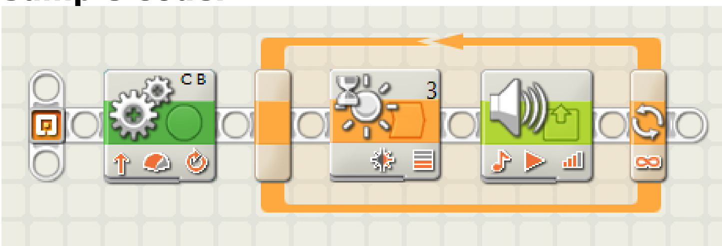
- Put 4-8 strips of electrical tape on the floor, spaced at least a few inches apart.
- For extra fun, put the strips of tape under a table and hang cloth around the edges of the table. The students won't be able see how many water deposits there are, and will have to wait for communication from the rover to find out.
- Make sure there is a high contrast between the tape and the floor/table.



Construction Tips:

- Point the light sensor down at the ground

Sample Code:



This program tells the rover to:

- Turn on motors C and B in the forward direction for an unlimited duration.
    - Don't go too fast – use the power slider to slow the rover down a little. This will make for more consistent light readings.
- Wait until the light sensor detects less light reflecting back from the surface (i.e. when it is over the dark tape). Change the sensor to wait until a darker light value ('<' symbol).
- Play a sound. You can select a sound file or a tone, but the sound should be short so that the rover doesn't miss the next line of tape.
- Loop back to waiting for the dark tape

Discussion Questions:

- How would you check to see if your rover is measuring the correct number of water deposits (since you can't go to Mars and see yourself)?
    - Set up a test run, where you put a known number of strips on the floor and run your rover over them, watching to make sure the rover beeps for every strip. Researchers test their robots using trial runs before sending them to Mars. Common Mars Rover testing grounds include Antarctica and desserts in Chile and the southwest US.

Additional Mars Rover Resources:

http://www.nasa.gov/mission_pages/mer/mer-20070521.html

This is an article about evidence for water on Mars.

11. FINAL ACTIVITY: MARS ROVER RACE

Goal: To iteratively design and build a Mars rover that can successfully navigate a Martian race course the fastest.

Overview:
This multi-day activity is a competition to design the fastest rover for searching Mars. Students will program a rover to navigate a simple race course, optimizing their route through the course (i.e. driving algorithm) to be the fastest. Then they will design a second program to solve an entirely new race course layout. The times needed to complete the two courses will be added to determine a winner.

Rules:

- The course is composed of 3 gates and a finish line.
    - The gates should be about 2 feet apart and randomly placed on the classroom floor.
    - The placement of the gates needs to be determined before the students start programming.
- The rover must pass through each set of gates, and then return to the start/finish line.
- The students can design their own route and instruct the rover to pass through the gates in any order.
    - Part of the challenge is picking the fastest route through the gates (i.e. driving algorithm). There will always be fast algorithms through the course and slow ones, based on how the gates are distributed across the floor.
- A rover can pass completely through a gate, and then back out of the gate. It does not have to continue forward.
- One rover at a time will navigate the course to accurately measure the time it takes.

Pre-Activity Setup:

- 3 sets of gates will need to be collected. They can be anything from matching soda cans, to pairs of books, hats, shoes, etc. It's helpful to keep the two objects marking the gate the same, i.e. two Coke cans for Gate 1, two Pepsi cans for Gate 2, two matching shoes for Gate 3, etc.
- A stopwatch for timing the rovers will also be needed.
- Tape can be used to mark the Start/Finish line.

Suggested schedule:
Note: Hold fewer or more rounds of different race courses depending on the number of days available for the final activity

- Day 1:
    - Build a simple rover
    - Start designing and programming the driving algorithm (i.e. the route for the rover)
        - Encourage the students to test out their program on the course as they're designing it.
- Day 2:
    - Finish the program, continuing to test the rover on the course.
    - Run the race course a few times for each rover. Record the best time for each rover.

    - Have the students write a summary of the results for their rover and algorithm (design of route through the gates, description of rover construction, any other iterations tried and lessons learned, etc)
- Day 3: with a new race course (gates randomly redistributed) design a new algorithm for the course
- Day 4: tally up scores (add the best times from each race course for each group), analyze different groups' algorithms and who had the fastest rover and why.

Major theme/discussion questions to answer:
- What makes the fastest team's rover win?
    - Is it the distance it covers?
    - Or the speed it travels?
    - Or the path they chose through the gates?
    - Did their rover travel in straight lines? Or curved lines?
    - How did the winning rover turn corners? How many turns did they make?

These are all factors the NASA scientists and engineers take into account when planning the design of the Mars rover (how fast it should go, how it should turn) and when planning the navigation route on Mars (what series of geologic features to visit on the planet's surface).