Measure the hallway yourself with a metric tape measure or meter stick. Students work well in pairs for this activity. If robots veer to one side or the other, adjust the rubber bands on the wheels or see instructions on page 5 along with the Calibrate Program at *http:www.smallrobot.com/speed/htm* (Also see HELP SHEET on next pages.)

Data tables are partially blank for students to choose their own labels and methods. A more directed approach would be to label the first table across the top with TRIALS, 100 CENTIMETERS, 200 CENTIMETERS. Number of trials could be listed down the first column. TRIALS, TIME, and DISTANCE could be used in the second table with the first column again labeled with number of trials.

Students can be left to invent ways to solve this problem on their own or they can be given some review on proportions or the DERT formula (distance = rate × time or d=rt). Also see the HELP SHEET on page 6. After the initial use of the meter sticks, it's helpful to store them away to avoid less mathematical solutions.

When measuring the hallway, the length of the robot (from the front bumper to the back) needs to be taken into account. This can be measured beforehand, calculated out in the hallway by running the robot the short distance of its own length, or sometimes an adjusted starting point can be used.

In the extension activity, one way to measure height is to have students lie on the floor with their feet against the wall and use the robots to measure how many seconds tall they are. Then use the DERT formula to convert to distance/height.

Height data can be organized in a stem-and-leaf plot.

Transfer a Program

To transfer a program from one calculator to another:

• Securely connect a link cable between the two calculators.

• RECEIVE Calculator: Press [2nd], then [LINK]. Use the arrow to highlight **RECEIVE**. Press [ENTER]. Wait for the other calculator to be set up and to send you the program/s.

• TRANSMIT Calculator: Press [2nd], then [LINK]. Use the arrow to scroll down to **3:Prgm...** Press [ENTER].

• Using the scroll arrow move the indicator arrow to the program/s to be transferred. Press [ENTER]. A program is selected if it has a black square in front of it.

• Use the scroll arrow to highlight "TRANSMIT". Press [ENTER]. The programs should be transmitted to the RECEIVE calculator.

The use of this function is suggested for transferring large programs (like CALI) only and not to eliminate programming practice for students.

The graph of TIME verses DISTANCE for this exercise should be a straight line that can be modeled by a linear equation. Students can make predictions by reading from the graph. Algebra 1 students or higher can use the slope formula and the slope–intercept model (y=mx+b) to find an equation for the best-fitting line. The y-intercept point (b) is zero. The slope of the line is determined by the speed or rate of the robot. From their slope–intercept equation, students can discover the formula for distance, d=rt.

The object that student robots come close to, but never touch, could be many things. For example: a wall, a house of cards, a small board with a tack that can fall and pop a balloon, or a line of dominos. The board and balloon challenge is exciting and works well. Students come to a testing area with only their robots and graphs. They are tested individually and given a randomly picked distance to start from in front of the board. Grades are given according to the scale on page 11. Whoever gets closest to the board for the class period can pop the balloon at the end. Participants should wear safety goggles.

Another approach is to simulate a Mars Rover doing planetary exploration. The robot has to go to the edge of a crater rim (tabletop) and peer down with a mock up bumper mounted camera to take pictures. The bumper must hang over the edge without the robot falling.

For more information on the Mars Orbiter Laser Altimeter see:
http://ltpwww.gsfc.nasa.gov/tharsis/mola.html
http://ltpwww.gsfc.nasa.gov/tharsis/mola.top10.html

A Planet X cliff face could be set up against a wall hidden from view with a curtain. Allow enough room for robots to travel underneath the curtain. A book or similar object could be used to simulate a rocky outcropping along the cliff face. Robots will reflect back more quickly from this region. Have the transect line (a meter stick works well) set parallel to the wall outside the curtain, but not more than 50 cm away. See CHALLENGE SET-UP diagram.

For **question one**, information from the Mars Exploration Rover Mission might be helpful: *http://marsrovers.nasa.gov/home/index.html*

For **question two**, you may want to avoid the newly discovered rocky outcropping region to avoid damage to your spacecraft.

For **question three**, answers will vary for part 1. In part 2, one way to improve accuracy is to shorten the increments along the transect line and take more samples. The MOLA emits 10 laser pulses per second.

For **question four**: 2.5 seconds divide by 2 = 1.25 seconds for the one-way trip and 300,000 × 1.25 = **375,000 km** (rate × time = distance) yields the distance from Earth to the Moon at that time.

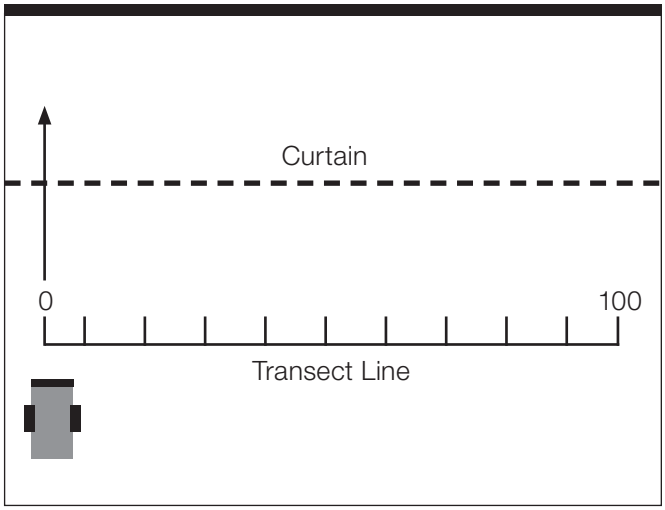
Question five is similar: 3.04/2 = 1.52 seconds, 22.32 × 1.52 = 33.9264 or approximately **34 centimeters**. Also see: *http://en.wikipedia.org/wiki/Lunar_laser_ranging_experiment*

From Planetary Features to Microscopic Creatures

Amazingly, the tapping atomic force microscope (AFM) uses the same basic principles that are at work on the MOLA and the robot exercise above. It has a cantilever that oscillates over extremely small surfaces and can make 3D images of bacteria, viruses, or even DNA. For more information see:

http://en.wikipedia.org/wiki/Atomic_force_microscope
http://en.wikipedia.org/wiki/Tapping_AFM

Challenge Set-up:



Because of the size of the bumper, the robot senses too large of an area. Another challenge for students could be to design a removable probe that could be attached to the bumper to sample a narrower area.

There are several ways to make the robot turn: one wheel stopped and the other moving forward or backward, one wheel moving forward and the other moving backward, et cetera. A sample right turn would be: Send ({120,42}) followed by Get (R). Hopefully by now most students are becoming comfortable programming robot movements on the calculator. However, if needed, a starter program that includes two straight runs with a right angle turn in between can be found in the PROGRAMMING INSTRUCTIONS. An alternative programming method is to use two programs and the recall command.

For example, first have students experiment with programming turns in their **GO** program from **Mission 1**, then have them program a straight run and a right turn. They can then create the new program **MAZE** and repeatedly recall sets of instructions from the **GO** program as follows.

From the new **MAZE** program press [2nd], then [RCL] . Press PRGM, then scroll over to **EXEC** and select **GO**. Press [ENTER] twice and the instructions from **GO** will be added to **MAZE**. Edit commands and times as necessary. This process can be repeated as many times as needed.

Sometimes just getting through the maze is challenging enough. One way to create a maze is to use meter sticks about a foot apart and included left and right turns. Place a paper cube (templates available on Internet) with a message inside at the end. A rolled piece of tape on the robot's bumper works for "picking up" the cube or Velcro strips or dots can be used.

For questions 1-3 answers will vary. The extension activity involves right triangles, the Pythagorean Theorem, and Pythagorean Triples. For **question 1**, the sides should be labeled 3 and 4 with a hypotenuse of 5. For **question 2**, the sides are 6 and 8. For **question 3**, the answer is 5. A linoleum floor composed of one-foot square tiles is helpful to visualize the right triangles formed by the robots' movements.

Another extension is to have students use their maze programming skills and have their robots duplicate the first iteration of the Jurassic Park fractal. See: *http://math.rice.edu/~lanius/frac/real.html*. *

* Used with permission of Cynthia Lanius

Estes Alpha Rocket bulk pack is useful for this exercise. When students are creating their mobile launch platform use all appropriate safety precautions. In this exercise, the MLP is only for transporting the rocket and not for launching

Follow all manufacturer's recommendations and the NAR's Model Rocket Safety Code when building and launching rockets. The early portions of the movie *October Sky* is informative as to what NOT to do when building and launching rockets.

As an added challenge, a 5% incline ramp could be added to the end of students' Crawlerways.

For **question 1**, the weight and placement of the MLB and rocket may change the traveling and turning characteristics of the robot. For **question 2**, at one mph NASA's Crawler-Transporter is traveling at 44.7 cm/s. It's faster by 24.7 cm/s. For **question 3**, answers will vary. The Crawler-Transporter uses hydraulic lifts to keep the Space Transportation System vertical as it goes up the incline at the launch pad.

The following Web sites may be helpful:

http://www.nar.org/NARmrsc.html

http://science.ksc.nasa.gov/facilities/crawler.html

http://en.wikipedia.org/wiki/Crawler-Transporter

http://www.cdli.ca/CITE/sts_rollout.htm

http://www-pao.ksc.nasa.gov/nasafact/count3teaf.htm

The first part of the lesson leads students to discover or reconfirm that the diameter of any circle fits around its circumference three and a bit times or pi (approx. 3.14):

By attaching a marker to different positions on the robot, various size circles can be created using wheel motions A or B as described on page 35. For wheel motion C (both wheels moving forward) attach a piece of string to the robot and secure the other end to a center point. As the robot travels around the center point, a circle can be drawn with a radius equal to the length of the string. An alternative method is to hold the robot on its side or to slide a small piece of pencil lead under the rubber band of one wheel and then hold the robot against a piece of paper.

For **question 3**, the diameter of a robot wheel is about 6.7 cm which makes the circumference of the wheel ($C = \pi d$, $C=3.14 \times 6.7$) approximately 21 cm. **Question 4** is approximately 21 cm. For **question 5**, the wheels need about 4.76 revolutions forward for the robot to travel 100 cm. **Question 7** is intended to lead students to the equation: circumference equals pi times diameter ($C = \pi d$).

Question 8 and **question 9** use the area of circle formula: area equals pi times the radius squared ($A = \pi r^2$). Using 3.14 for pi gives a rounded answer of 38.47 cm^2 for question eight and 4 m for question nine. For **question 10**, answers will vary. In the book *Contact*, prime numbers were used as a basis for communication.

A clearly drawn circle about 32 to 40 cm in diameter will be needed for **Mission 5**.

The parallel universe information is based on the article "Parallel Universes" by Max Tegmark in the May 2003 *Scientific American* magazine, page 40.

Award points as you see fit for the Table 3 activity. At the end of the activity, one way to reward the top individuals or teams with the highest total is allow them to pick a prize box. Three mystery prize boxes can be made ahead of time, one with 2-3 pencils, one with one pencil, and a dud prize. Similar to the game show *Let's Make a Deal*, the teacher can offer to "buy" a box back after it has been chosen. Probability can be discussed as each box is chosen.

For **questions 1** and **2** treat the numbers on the spinner board as being all positives. The answer to number one is 1/4 and the answer to number two is 1/2. Many other types of probability questions can be asked such as, asking for the probability of landing on a multiple of 2 or 3, a perfect square, etc.

For game 5, a Moon Walker or similar walking robot is available at a variety of scientific supply stores.

For the Relay Race the following program might be helpful:

```
PROGRAM:RELAY
:Send({211})
:Get(R)
:Send({100,50})
:Get(R)
:Send({120,92})
:Get(R)
:Send({222})
:Get(R)
```

This program is for a robot waiting to be tagged. Start the program and the robot will wait until its bumper is hit, backup, then turn 180° (as always adjust the time of the turn as necessary), and run forward until it tags the next robot or crosses the finish line. See if students can write a program that cuts time off their run. For instance, the second through fourth robot can simply back up when "tagged." The starting robot in the relay only needs the commands:

```
PROGRAM:START
:Send({222})
:Get(R)
```

King of the Ring was the most popular game with students. They used strategies of charging, withdrawing, charging again, and turning to knock opponents out of the ring. The Relay Race was also very exciting for the students and graphically demonstrated why scientists test and test again. There are many opportunities for Murphy's Law to sneak into this activity.

For mission patches see:

Activity
http://nasaexplores.nasa.gov/show_58_teacher_st.php?id=040526104107

Students may need encouragement to pick different activities for their reports. In addition to missions and exploration extensions, consider topics such as:

Murphy's Law and Robotics - Whatever can go wrong will go wrong

Basics Robotics - How to Operate a Calculator Robot

Synchronized Robot Dance

Robot Art

Rescue Robots

Besides showing what they've learned, there is an opportunity for students to demonstrate communication standards in this activity. You may want to invite parents, other teachers, and your principal to see the patches, posters, and presentations.

How to create a spectacular chain reaction demonstration using ping-pong balls can be found at: *http://www.ap.stmarys.ca/demos/content/modern/mousetrap_reactor/mousetrap_reactor.html*

ThinkQuest's Nuclear Processes home site has links to student level information on this topic: *http://library.thinkquest.org/17940/index.html*

Book reference: *E=mc²: A Biography of the World's Most Famous Equation*, by David Bodanis. For more information on the Norwegian Resistance and Germany's nuclear efforts during World War II see: *http://www.pbs.org/wgbh/nova/hydro/*

For more information on Radioisotope Thermoelectric Generators see: *http://en.wikipedia.org/wiki/Radioisotopic_Thermoelectric_Generator*

In standard form, $299{,}792{,}458^2$ equals:
89,875,517,870,000,000
With the scientific notation decimal rounded to the second places, 2^{80} in standard form equals:
1,210,000,000,000,000,000,000,000.

For **question 1**, other applications of $E=mc^2$ include: nuclear submarines, nuclear power plants, smoke detectors with radioactive americium inside, red-glowing emergency exit signs with radioactive tritium inside, some medical diagnostic devices, radiation treatment of cancer, carbon-14 dating, and our sun. See pages 192-194 in Bodanis' book.

For **question 2**, the energy produced by the sun makes our planet habitable. This energy is produce by nuclear fusion where hydrogen atoms are combined to make helium. Also see nuclear fusion at the ThinkQuest Web site.

For **question 3**, in scientific notation 90,000,000,000,000,000 equals 9.0×10^{16}.

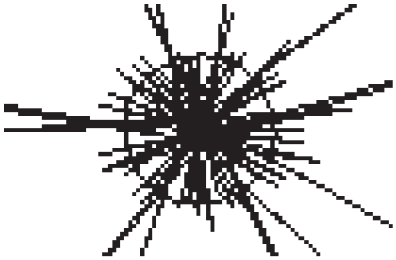
For **question 4**, answers will vary.

This activity provides a fun way to explore functions and an opportunity to extend concepts while encouraging artistic design.

Alfred:

George:

Exploding Star:



You'll need to have some students make a cardboard Mars landing vehicle and some fuzzy "rock" that can be picked up by Velcro. For information on the Mars Exploration Rover Mission, see: *http://marsrovers.jpl.nasa.gov/home/* and *http://en.wikipedia.org/wiki/Mars_Exploration_Rover*.

For **questions 1**, six wheels generally make a vehicle more stable and in the case of the Mars Exploration Rovers, with extra steering motors front and rear, they enable the Rovers to turn in place, a full 360 degrees. (Also see Drive system at the Web site above.) For **question 2**, answers will vary. For **question 3**, the answer is approximately 22.57 hours.

```
Program: EXPLORE2
    ClrHome
    Lb1 A
    getKey->X
    If X=73: Goto 1
    If X=93: Goto 2
    If X=82: Goto 3
    If X=84: Goto 4
    If X=74: Goto 5
    If X=94: Goto 6
    If X=72: Goto 7
    If X=92: Goto 8
    If X=83: Goto 9
    If X=105:Goto 1
    0
    Goto A
    Lb1  1
    ClrHome
    Output (4,5, "FORE
    WARD")
    Send ({122,99})
    Get (R)
    Goto A
    Lbl 3
    ClrHome
    Output (4,7, "LEF
    T")
    Send ({102,43})
    Get (R)
    Goto A
    Lbl 4
    ClrHome
    Output (4,6, "RIG
    HT")
    Send ({120,42})
    Get (R)
    Goto A
    Lbl 2
    ClrHome
    Output (4,5, "BAC
    KWARD")
    Send ({100,99})
    Get (R)
    Goto A
    Lbl 5
    ClrHome
    Output (4,5, "FOR
    RIGHT")
    Send ({120,22})
    Get (R)
    Goto A
    Lbl 6
    ClrHome
    Output (4,4, "BAC
    KRIGHT")
    Send ({120,67})
    Get (R)
    Goto A
    Lbl 7
    ClrHome
    Output (4,5, "FOR
    LEFT")
    Send ({102,22})
    Get (R)
    Goto A
    Lbl 8
    ClrHome
    Output (4,5, "BAC
    KLEFT")
    Send ({102,67})
    Get (R)
    Goto A
    Lbl 9
    ClrHome
    Output (4,6, "DEF
    ENCE")
    Send ({120,99})
    Get (R)
    Send ({102,99})
    Get (R)
    Goto A
    Lbl 10
    Stop
```

For the CHALLENGE activity, two 84-inch cables connected together are useful for extended range. The 84-inch data cable (7.5 foot CBR **I/O** cable) can be found at:

http://epsstore.ti.com

Follow links to TI-83 or TI84 accessories

Test Questions:

1. Time=11.75 seconds (rounded):
D=rt, 205=17.45t, solve for t.

2. Diameter=15 inches: C=πd, 47.1=3.14d, solve for d.

3. Area=3.14 square meters: A=πr2, A=3.14(1^2),
solve for A.

4. Probability=3/8: One 10 and two 8's out of eight possible choices or P(A)=n(A)/n(S), P(A)=3/8.

5. Answers will vary: Open ended questions.

6. Energy=$1.8X10^{17}$ joules: $E=mc^2$, E=2($300,000,000^2$),
solve for E.

7. The program should look something like this:

```
PROGRAM:LIFELINE
:Send({122,225})

:Get(R)
:Send({120,21})
:Get(R)
:Send({122,250})

:Get(R)
:Send({102,21})
:Get(R)
:Send({122,500})

:Get(R)
:Stop
```

8. Hypotenuse=13 feet: $a^2+b^2=c^2$, $5^2+12^2=c^2$, solve for c.

9. Questions:
   a. Moves straight-line graph five units up the y-axis.
   b. Moves an absolute value graph three unit to the left on the x-axis.
   c. Moves parabola three units to the right on the x-axis.

10. Answers will vary: Open ended question.

PopBots is an exciting activity and a fun way to finish the class. A small pump to inflate balloons is useful and the safety issue of sharp pencils needs to be addressed before the activity begins. Safety goggles should be worn by all involved.