Note to the Teacher

In this investigation students will identify a relationship between the size of the wheel and the distance traveled when the number of rotations of the motor axles remains constant.

Students are required to measure the distance and record the value in inches. Five trials are run for each condition (wheel size); students then find an average distance value for each condition. Extension activities involve converting inches to centimeters, calculating circumference, and predicting values by interpolation. Students are required to write conclusions and answer questions about what they learned.

Note that, while the Investigation includes the use of a rotation sensor (not included in the Basic Kit), IT IS NOT REQUIRED FOR RUNNING THE INVESTIGATION. See the Helper Section at the end for further instructions.

Description of the investigation

In this investigation, students will begin with a standard Squarebot and modify it as shown in the Helper Section. They will then open a program that moves the vehicle forward for a given number of rotations of the motor axles, download the program to the robot, and test to see how far the robot travels. Students will repeat this procedure 5 times. After these five trials, they will change the diameter of the wheels and repeat the procedures. They will test all three wheel configurations.

• Hypothesis: If the number of rotations of the motor axles is held constant, then a larger diameter wheel will move the vehicle a proportionately greater distance.

• Variables

- Control: number of rotations of the motor axles
- Independent: wheel size (3 different diameters are available)
- Dependent: distance traveled.

Time Required

Approximately 3-4 periods

VEX KITS AND PARTS NEEDED

1. VEX Protobot Kit
2. Hardware and Metal Kit
3. VEX Microcontroller
4. Programming Hardware Kit
5. ROBOTC software
6. 1 VEX Encoder (For alternate lesson without Encoder, see page 8) OR

1. VEX Superbundle Kit (Superbundle contains all items above)

Additional Materials

(see Helper Section for more information)

• Smooth floor area

• Meter/yard ruler or tape measure

• Masking or electrical tape

Note to the Teacher

Procedures for Wheel Size Matters

1. Prepare the test bed (including a starting line taped on the ground).
2. Modify the Squarebot as instructed in Lesson/Procedures.
3. Open and download a program that makes the robot run a certain number of motor axle rotations.
4. Download the program to the Squarebot.
5. Mark the beginning point (front of the Squarebot) with a piece of tape on the floor.
6. Run 3-5 trials for each condition, switching between the three types of rear wheels.
7. Record the distance traveled for each trial.
8. Compute an average distance traveled for each of the three conditions.
9. Measure the diameter of each of the 3 wheels in inches.
10. Plot Wheel Size (inches) vs. Distance Traveled (inches)

Standards Addressed

Science Standards

- Content Standard "A" Science as Inquiry
- Content Standard "B" Physical Science
- Content Standard "E" Science and Technology
- Unifying Concepts
  - Systems, Order, and Organization
  - Evidence, Models, Explanation
  - Constancy, Change, and Measurement
  - Evolution and Equilibrium

Math Standards

- Numbers and Operations
- Algebra
- Geometry
- Measurement
- Problem Solving
- Reasoning and Proof
- Communications
- Connections
- Technology Standards
- The nature of Technology Standards 1, 2, 3
- Design 8, 9, 10
- Abilities for a Technological World 12
- The Designed World 16, 17

Math versus Science

As students complete the investigations, they will begin to understand the relationship between mathematics and science. Mathematics is pure; when you

Note to the Teacher

plug numbers into equations, you will get the same result every time. Science, on the other hand, is dependent on multiple variables that may or may not be in control of the investigator. A good scientist will eliminate as many uncontrollable variables as possible so that they are able to analyze and measure the results of their investigation.

Experimental Error

There are many things that can cause your experimentally measured numbers to fall off-target from the predicted values. Here are a few:

- Systematic error

  Systematic error always affects data the same way; in other words, it will make the data either larger or smaller, but not both. The following are examples of systematic error:

  Stopping Distance: Due to its momentum, the robot does not come to an instantaneous stop. Robots that are moving faster will take more time, and hence more distance, to stop.

  Friction: While moving, friction works to slow your robot.

- Random error

  Random error has variable effects on data; in other words, it may make the data larger sometimes and smaller other times. The following are examples of random error:

  Wheel Slippage: At higher speeds or during acceleration, wheels are more likely to slip relative to the ground. This results in a shorter distance being traveled. Often, wheels will slip unevenly on different sides of the robot, making the robot move along a curve rather than a straight line, which makes it difficult to measure how far it's gone.

  Battery Power: The battery power will change due to various factors. This can have a noticeable effect on the speed of the robots.

Analysis and Conclusions

Answers are shown in italics.

1. Compute the averages for each condition on the data table (see extension activity 1 & 2 below).

The average distance is the average of the five individual distances for each condition.

2. Draw a plot of Wheel Diameter (inches) vs. Distance Traveled (inches) based on these averages.

Note to the Teacher

A Typical Basic Investigation Plot:

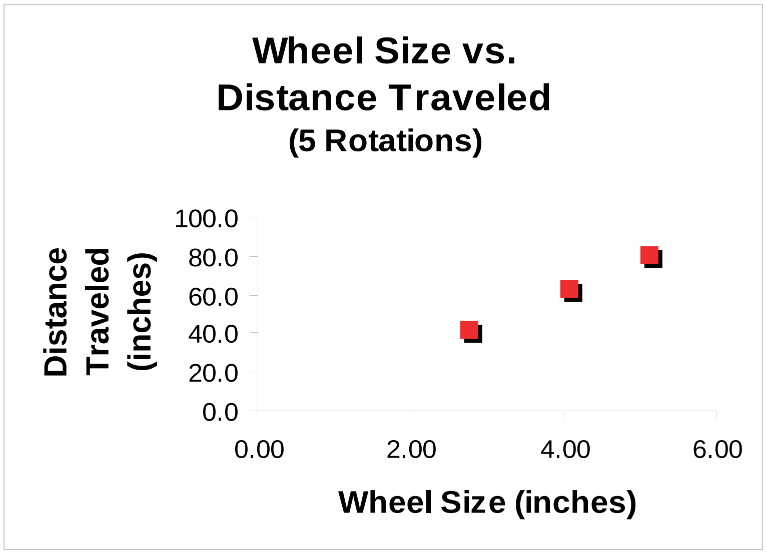


Figure 1: Typical Data from 5 Rotations (note: program runs for 10 rotations)

3. What is the hypothesis of this lesson? Did your result support or refute the hypothesis? Explain.

Hypothesis: If the number of rotations of the motor axles is held constant, then a larger diameter wheel will move the vehicle a proportionately greater distance.

The hypothesis is clearly supported by the data. Larger wheels travel farther than smaller wheels in the same number of rotations.

4. Why did the robot travel different distances in Fig. 1?

The program for this investigation runs for a constant number of motor rotations, which means that the wheel will spin the same number of times regardless of size. A larger wheel, however, has more circumference than a smaller wheel, which means that the robot will travel farther forward per turn of the wheel. You can think of the relationship as "unrolling" the circumference of the wheel onto the ground to get the distance traveled; a larger wheel would "unroll" over a longer distance per rotation, and so goes farther in the same number of rotations.

5. Imagine the robots were placed on a different surface (i.e. carpet, table, floor, etc.). Would this change the distances the robots traveled? Why?

The robots may travel different distances than they did in this investigation because different surfaces cause different amounts of wheel slippage. The difference is NOT caused by the fact that the robot can go faster on some surfaces than others due to friction, because the robot is traveling for a set number of rotations, and speed makes no difference. It IS caused by the fact that a wheel can slip and still turn, but not move the robot forward. Imagine a robot running on ice – the wheels could be spinning at full power, but the robot could be staying absolutely still. While not to the same extreme degree, wheels will slip smaller amounts on other surfaces as well,

Note to the Teacher

some more than others.

One more important point to note is that regardless of how much the wheels slip, if the slippage is constant, larger wheels will still go farther than smaller wheels (unless there is some other factor present, like the amount of traction that a given wheel or tread type has).

Practical Applications:

We ought to be able to explain to students why we teach certain subjects. One good way to do this is to propose practical applications for the material. The following are good examples:

- Automobile owners sometimes modify their vehicles by changing wheel and tire sizes. What must be considered when making this alteration?

  If the diameter changes, the speedometer and odometer must be recalibrated.

- An understanding of this lab prepares the student for work with gears and ratios.

When Completing this Lesson, Students Will Be Able to:

(including all Extension Activities)

1. Build a robotic test bed or prepare a test area on the floor.
2. Modify a Squarebot as per Helper Section
3. Download a program that runs the motors for a given number of rotations of the motor axles.
4. Run the investigation using 3 different conditions (i.e. wheel sizes)
5. Collect data and record it on a data table.
6. Convert between centimeters and inches.
7. Calculate wheel circumferences from measured diameters.
8. Calculate wheel diameters from # axle rotations and distances traveled using the circumference formula.
9. Apply and clarify various points of experimental procedure:
   a. Experimental hypothesis
   b. Measurement technique
   c. Multiple trials and average values
   d. Systematic Error
   e. Random Error
10. Analyze data and draw conclusions.
11. Calculate distances the robot may travel based on interpolation and extrapolation of existing data.
12. Write up a summary of lessons learned in the investigation.

Extension Activities: Summary

EXTENSION ACTIVITY 1: Conversion of Units

In this activity students are given distances in inches and convert those values to centimeters.

EXTENSION ACTIVITY 2: Calculation of Circumference by Measuring Diameter

Note to the Teacher

In this extension activity, students measure the diameter of the wheel and calculate its circumference.

EXTENSION ACTIVITY 3: Prediction by Interpolation and Extrapolation

In this extension activity, students plot the data, and are expected to predict values *in between* the known values. This is accomplished by interpolation, defined as a method of constructing new data points from a set of known data points. They also extrapolate values. Extrapolation is a type of interpolation in which predictions are made *beyond* (above or below) the known set of values.

Extension Activities: Detail

Calculation of Circumference by Measuring Diameter and Conversion to cm

A table with a typical set of values for one condition:

Condition # (Wheel Size)		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
1 (small)	in.	44½	42¼	43½	42¾	41½	42.9
	cm.	113.0	107.3	110.5	108.6	105.4	108.9

1. Convert the distance the robot traveled from inches to centimeters for each trial in Condition 1 and fill in the appropriate row in the data table.

Inches can be converted to centimeters by multiplying by 2.54. Shown below are the conversions using the factor-label method.

44.5 in x (2.54 cm / 1.00 in) = 113.0 cm

2. Describe the differences between the original Squarebot and the one used in Condition 2.

The wheel size has been increased.

Extension Activity 3: Prediction by Interpolation and Extrapolation

Figure 2: A typical plot for interpolation with a “best fit” line added, either through visual estimation or using an Excel “trendline”.

Note to the Teacher

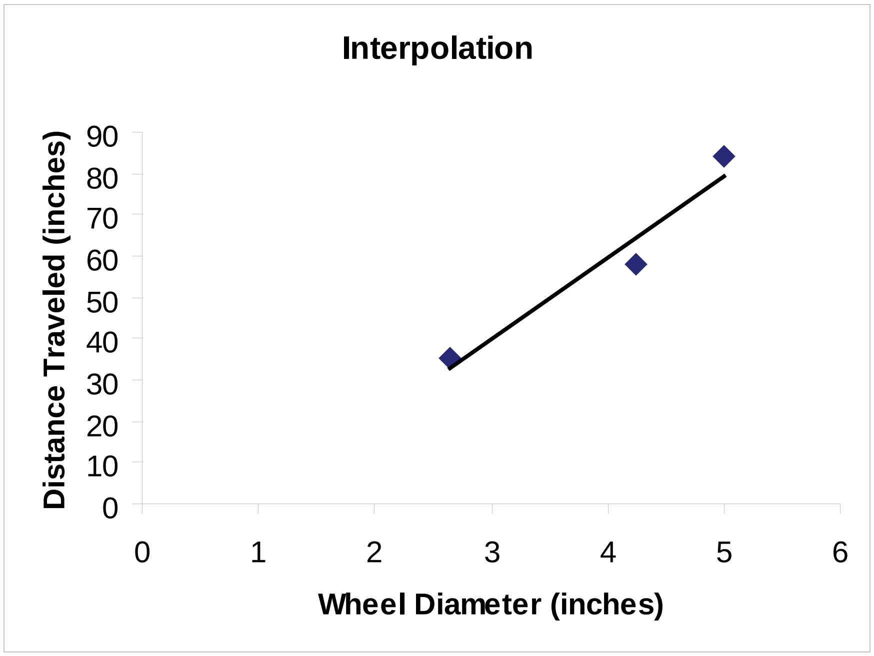


Figure 2: Interpolation

3. Suppose you used a wheel that was larger than the medium, all-purpose tire (Condition 2) but smaller than the large, knobby tire (Condition 3), approximately 4 inches in diameter. Based on Figure 2, about how far might you expect the Squarebot to go?

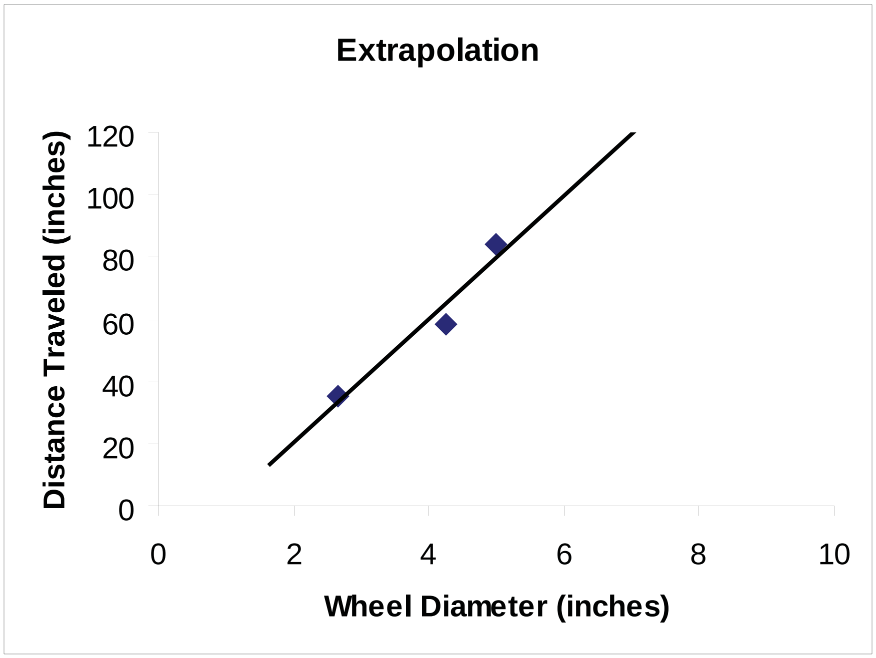
The robot would go some distance between the Condition 2 distance and the Condition 3 distance. In our sample data shown above, that means it would go somewhere between 59 and 84 inches, with the precise distance depending on the exact size of the wheel. A good estimate on this plot would be 60 inches. Students determine this value by actually drawing a vertical line up from the 4 inch diameter to the line, then drawing a horizontal line over to the Y-axis.

4. Will the Squarebot in the example above always go this distance? Why or why not?

No, it won't always go the same distance; see "Systematic and Random Errors" for the various reasons. In addition, interpolation depends on the quality of the data. Data points in a line like the Basic Investigation plot above tend to be reliable. However, if the data are not lined up as well, as in the Interpolation plot above, then predictions may not be as reliable.

Figure 3: a typical plot for extrapolation with a "best fit" line added:

Note to the Teacher



5. Suppose you had a wheel that was even larger than the large, knobby tire (Condition 3), approximately 7 inches in diameter. About how far might you expect the Squarebot to go?

The robot must go farther than the Condition 3 distance (84 inches in the sample data), with the precise distance determined by the exact size of the wheel. A good estimate on this plot would be 115 inches. Students determine this value by actually drawing a vertical line up from the 7 inch diameter to the line, then drawing a horizontal line over to the Y-axis.

Note that this means we can still draw conclusions about data outside the range we have actually measured, i.e. make extrapolations based on measured data.

6. Will the Squarebot in the example above always go this distance? Why or why not?

No, it will not. See the similar question for the Interpolation plot above.

Helper Section: Running the Lesson Without the Rotation Sensor

The Rotation Sensor is NOT required.

An alternate, but equally valid, method for this investigation is to use a CONSTANT TIME PERIOD rather than a set number of rotations as described above. Procedures are below.

1. Follow the instructions for modifying the Squarebot in the construction shows; simply ignore references to the rotation sensor.

2. Open ROBOTC, open a new program, and copy and paste the code below into the page.

Note to the Teacher

```
task main()
{

motor[port2] = 127;
motor[port3] = 127;
wait1Msec(2000);

}
```

3. Turn on the robot. Select Robot/Compile and Download.

4. You will be asked to save the program somewhere. Do so.

5. Turn the robot on and off to run the program. (NOTE: if you click Start on the Debugger interface, the robot will not run.)

Using the method described above will likely lead to greater error due to the fact that battery power can vary substantially over a relatively short period of time. However, as noted in the introduction, the relationship of wheel size to distance traveled is a critical point in this investigation, and the results should still support the hypothesis. Therefore, once the timer program above is downloaded to the robot, continue the investigation as described in the lesson procedures.