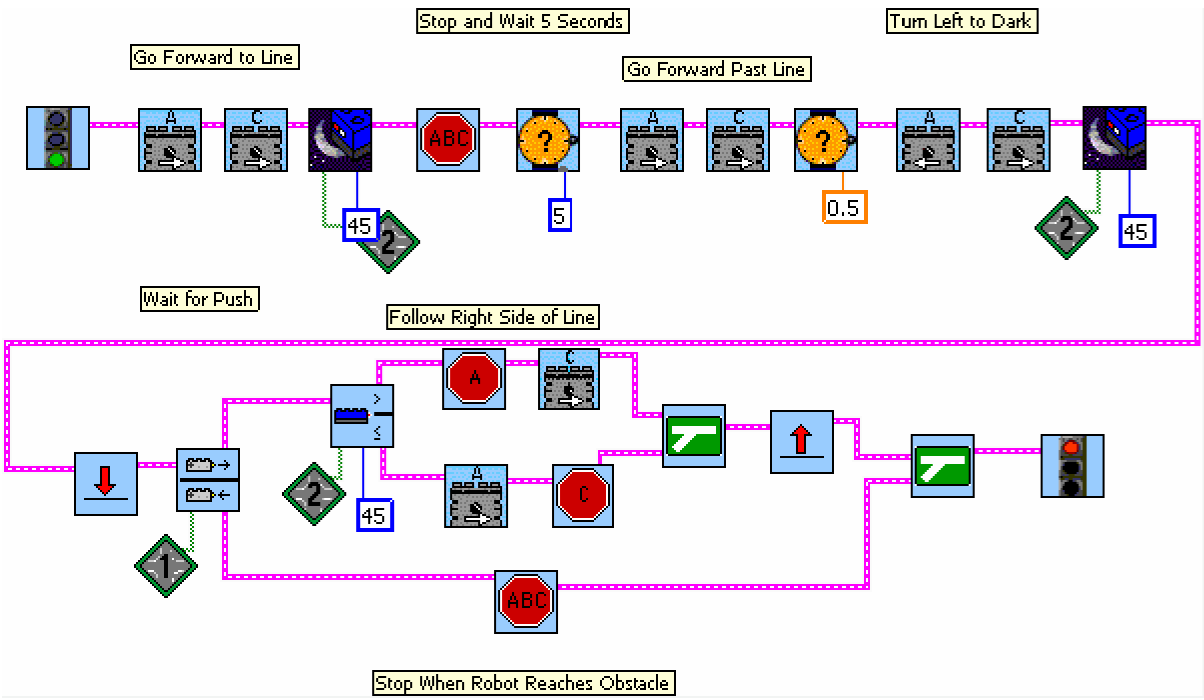
Answer Guide
Probe Workbook Activities

Activity 1 – Robot Garage

Pseudocode

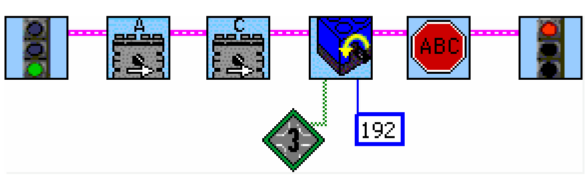
Go forward until you see dark
Stop
Wait five seconds
Turn Left
Follow line until touch sensor is pushed
Stop

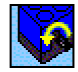
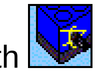
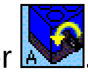
Program



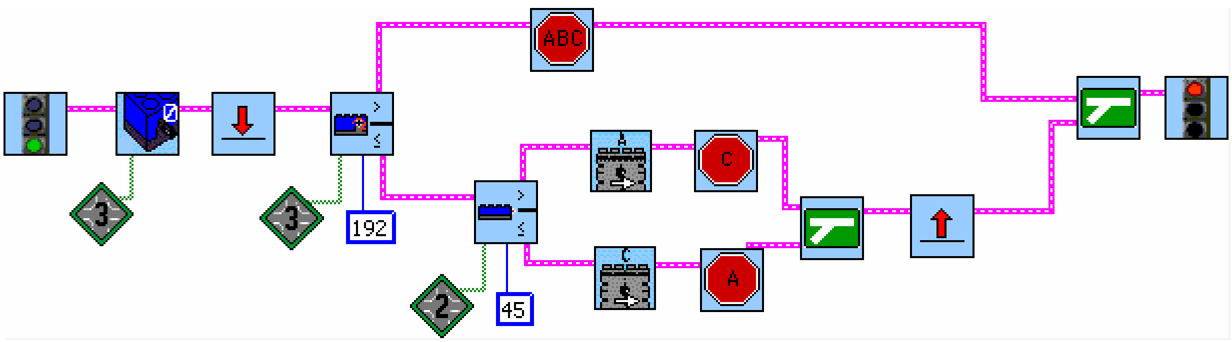
Activity 2 – Do it Again, Robot

In writing this program, it was assumed that each revolution of the rotational sensor moved the robot forward 1 inch. Since there are 16 clicks per revolution, you would need 12 x 16 or 192 clicks to go forward for 12 inches.



Be careful when using the rotational sensor icon. Don't confuse  with  or . The first icon is the Wait For Rotation icon where there are 16 clicks per revolution. The second icon is the Wait For Angle Icon where there are 360^o in a circle and the third icon is the Wait for Rotation without Reset icon. As you've seen with the timer fork, you need to reset the clock before you can use it because the clock starts to run the second you hit the Run Button on your RCX. Similarly, the Rotational Sensor starts to count the moment the robot starts to move. The Wait For Sensor icon automatically resets the counter. Only if you want to use the sensor without resetting it should you use the last icon. Also, remember that there are no 'partial clicks' so when you program your robot, you'll need to pick the number of clicks that is closest to distance you want to use.

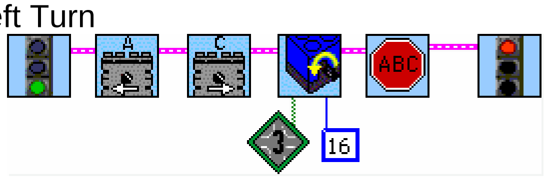
Activity 3 – Tracking With a Twist



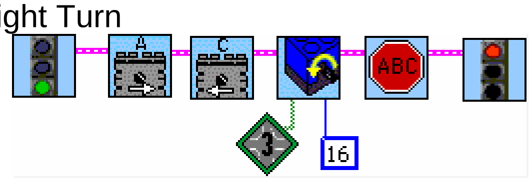
Remember, you need to reset the rotational sensor before you use the Rotational Sensor Fork, just as you need to reset the timer before you use the Timer Fork.

Activity 4 – Measured Turns

90^o Left Turn



90^o Right Turn



One thing to always keep in mind when using the rotational sensor – Always Make Sure the Sensor is on an Active Wheel. What does this mean? It means that the sensor has to be on a wheel that is powered. When you're making a point turn, this isn't a concern because both wheels are active (one is going forward and the other is in reverse). You have to be careful when you're making a non-point turn where one wheel is stopped. When you built your rotational sensor on your robot, you put it on the right wheel. If you make a forward, non-point right turn, Motor ‘A’ (on the left) is turning forward and Motor ‘C’ is stopped. If your rotational sensor in on the right wheel, then it may not turn, and if you’re turning until the rotational sensor gets to a certain number of clicks, your robot may never stop. How do we solve this problem? Easy! When you are making a right non-point turn, you just have to program your robot to make a reverse non-point turn – that is with Motor ‘A’ stopped and Motor ‘C’ running in reverse.

Activity 5 – Gears Galore!

Gear Identification

Upper Left – Slip Clutch
Upper center – Differential
Upper Right – Spur Gear
Lower Left – Idler Gears
Lower center – Bevel Gear (also called a Crown Gear)
Lower Right – Worm Gear

Activity 6 – Go the Distance

Gears and speed/time
In this investigation youth will learn how changing the gear ratio on a robot’s drive train affects how far it will travel. The control variable in this lesson is the amount of time the robot’s motors remain on. The motors will be powered for three seconds and turned off. The first time the robot is run, using a 1-1 gear ratio, the youth will measure the distance traveled and record that value. They will follow this same procedure for the next two conditions; 5-1 & 3-1 gear ratios. They will compare the distances traveled in each condition to the gear ratio for the condition and see if there is a mathematical relationship.

The surface that you run your robots on will affect the distance traveled.

Math Versus Science
As youth complete the investigations they will begin to understand the relationship between mathematics and science. Mathematics is pure; when you plug numbers into equations you will get the same result every time. Science is dependent on multiple variables that may or may not be in control of the investigator. Good scientists 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 is something in the experiment that always throws off the data in the exact same way. In this experiment, the momentum of the robot carries the

robot further than the investigator wants. This may be fixed by lowering the motor power level.

- **Random error**
  Random error is caused by small factors that constantly change and affect the experimental results. In this experiment, random error may be caused by too much friction, slippage, test surface, varying starting points, sloppy measuring procedures, or battery level.
- **Friction**
  While moving, friction works to slow your robot. Robots with higher speeds not only encounter more friction from the ground, but in our case, they also have less torque due to their lower gear ratios. Less torque means that the robot is less able to push itself along, and will consequently suffer a greater speed loss.
- **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.
- **Acceleration time**
  We calculate an average speed, but in truth, the robot needs time to accelerate to its actual top speed. With lower torque configurations, this time becomes significantly larger, and the average speed suffers.
- **Stopping distance**
  The robot does not come to an instantaneous halt when instructed to stop. Instead, the motors begin braking, but the actual stopping takes time, which translates into additional distance moved. Robots that are moving faster will take more time, and hence more distance, to stop.

This unit includes a worksheet where youth capture data and write conclusions; on the following pages you will find the answer key for the worksheet.

“Gears and Speed – Constant Time” Answer Key

Red = exact answers
Magenta = sample

Condition	Number of Teeth on Gear on Motor	Number of Teeth on Gear on Rear Axle	Gear Ratio between Motor Axle and Rear Axle	Length Of Time The Robot Moves (sec)	Distance Tankbot Traveled (cm) [3 Trials]	Average Speed for Each Trial (cm/sec)	Overall Average Speed for Condition (cm/sec)
1	24	24	1:1	3	1. 215	1. 71.7	72.8
					2. 216	2. 72.0	
					3. 224	3. 74.7	
2	8	40	5:1	3	1. 47	1. 15.7	15.9
					2. 48	2. 16	
					3. 48	3. 16	
3	8	24	3:1	3	1. 79	1. 26.3	26.0
					2. 77	2. 25.7	
					3. 78	3. 26.0	

Condition 1:

1. The back of the starting line is where the front of your robot was at the beginning of the run. At the end of the run, you measured to the front of the robot again. Why is it important to always measure to and from the same point on the robot?

   Youth will often intuitively measure the distance from the back of the robot to the front of the line, because it’s the distance “between” the two.

   A quick illustration of why this is wrong: imagine a robot design so long that it doesn’t even cross the line, even if it has moved the correct distance. What is your distance then? Clearly you can’t measure the closest point between the robot and the line anymore, because the robot isn’t even off the line. And you can’t say that the robot has failed to move, because it certainly did move. The only way to fairly measure how far the robot has gone is by comparing how far the same point on the robot went; in the investigation, it is the front of the robot to the front of the robot.

2. Fill in the following values in your data table.
   a. Number of teeth on the "motor" gear for this condition.
   b. Number of teeth on the "wheel" gear for this condition

   These are direct observation by counting the number of teeth on the gears.

   c. Gear ratio for this condition

Gear ratio is calculated with toothed gears by taking the fraction:

$$\frac{\#\ of\ \ teeth\ on\ driven\ gear}{\#\ of\ \ teeth\ on\ driving\ gear} = \frac{\#\ of\ \ teeth\ on\ "wheel"\ gear}{\#\ of\ \ teeth\ on\ "motor"\ gear} = \frac{24}{24} = 1$$

d. Number of seconds the robot runs for this condition

This is 3 seconds in all conditions, set by the program.

3. Calculate the average speed for each trial in this condition, and fill out the appropriate cells in the data table.

Average speeds are calculated by taking the distance traveled for each trial in the condition, and dividing by the amount of time it took to travel that far. There should be one average speed for each of the 3 trials in this condition.

Trial 1 - 215cm / 3 sec = 71.7cm/sec
Trial 2 - 216cm / 3 sec = 72.0cm/sec
Trail 3 - 224cm / 3 sec = 74.7cm/sec

4. Calculate the overall average speed by averaging the speeds from each of the three individual trials. Fill out the appropriate cell in the data table.

The overall average speed is the average of the three calculated speeds. Its purpose is to give you a number that has less random variance in it than the individual measurements.

(71.7 + 72.0 + 74.7) / 3 = 72.8cm/sec

5. Answer the following questions:
    a. How many times does the gear on the motor have to turn for the wheel to make one full rotation?

        The motor gear turns once per turn of the wheel gear. You can find this either by direct observation, or by calculation based on the gear ratio.

    b. How is this number related to the gear ratio for this condition?

        The number of motor gear turns per wheel gear turn is the same as the gear ratio by definition. Observationally, youth should still be able to see that they are the same.

Condition 2:
6-9. See #2-#5.

Condition 3:

10. What happened? What change did we make to the robot that caused this change in behavior?

    Adding an idler gear into the robot's gear train causes a reversal in the direction of rotation, which is observable as the robot moving backwards rather than forward.

11. What would happen if we added a second idler gear between the 40-tooth gear and the 24-tooth gear?

    Adding another idler gear would cancel the effect of the first one, because it would "double-reverse", i.e. the two reversals would negate each other.

12. What happened when you reverse the polarity on a motor? How does this help with our problem?

    Reversing the polarity on a motor reverses its direction, just like adding an idler gear. By having both an idler gear and a polarity reversal, we have effectively reversed twice, and the two cancel each other out.

13-16. See #2-#5.

Analysis and Conclusions:

17. In which experimental condition did your robot move fastest?

    The robot with the lowest gear ratio, the 1:1 gear ratio in Condition 1, should be fastest by a large margin.

18. In which experimental condition did your robot move slowest?

    The robot with the highest gear ratio, the 5:1 gear ratio in Condition 2, should be slowest by a clear margin.

19. Answer the following questions:
    a. Write a fraction comparing the speed in Condition 3 to the speed in condition 2.

       Youth should come up with a fraction close to 5/3 if their data was good.

    b. Convert your answer to a decimal number.

       Straight decimal conversion of the fraction from part a. (1.67)

    c. Round the decimal to the nearest whole number.

       Straight whole number rounding of the decimal from part b. (2)

20. Answer the following questions:
   a. What is the ratio of speeds between the robot in Condition 1 and the robot in Condition 2?

      5:1 theoretical, about 4.5:1 measured.

   b. What is the ratio of gear ratios between the 2 robots?

      (Gear ratio of Condition 1 / Gear ratio of Condition 2) = 1:5

   c. How are speed and gear ratio related, based on this comparison?

      There are many ways to express the same mathematical relationship, and some Helpers may wish to forego the specific numeric relationship in favor of the qualitative relationship.

      Qualitatively, speed goes up as gear ratio goes down, and goes down as gear ratio goes up.

      Quantitatively, $Speed = \frac{1}{Gear\ Ratio} \times speed\ with\ 1:1\ gear\ ratio$, which is a relationship called by many names, including “inversely proportional”, “proportional to the reciprocal”, and “one over X”. Essentially, it means that if you multiply the gear ratio by some number, the speed will be effectively divided by the same number, and vice versa.

21. Answer the following questions:
   a. Predict the speed of the robot in Condition 3 based on its gear ratio and the speed you measured for Condition 1.

      This is an interpolation/data verification question, asking youth to make a prediction based on data they have, and check it against an actual measurement they already have. This sort of calculation is often performed by scientists in order to prove the reliability of their experimental methods.

      The gear ratio in Condition 3 is 3 times the gear ratio in Condition 1, so the speed in Condition 3 should be 1/3 times as much as in Condition 1. Based on sample data:

      $$Prediction = 72.8cm/\sec \times \frac{1}{3} = 24.3cm/\sec$$

      Algebra
      The exact method by which we derive this relationship can be solved by beginning with a simple equality that expresses what the theoretical (and observed) relationship between 2 different robots with different gear ratios.

We start with the equation:

$$(Condition\ 1\ Speed) \times (Condition\ 1\ Gear\ \ Ratio) =$$
$$(Condition\ 3\ Speed) \times (Condition\ 3\ Gear\ \ Ratio)$$

We then solve for Condition 3 speed in the equation.

$$Condition\ 3\ Speed = Condition\ 1\ Speed \times \frac{Condition\ 1\ Gear\ \ Ratio}{Condition\ 3\ Gear\ \ Ratio}$$

And finally, we plug in numbers to solve the equation.

$$Condition\ 3\ Speed = Condition\ 1\ Speed \times \frac{Condition\ 1\ Gear\ \ Ratio}{Condition\ 3\ Gear\ \ Ratio}$$

$$= 72.8 cm/sec \times \frac{1}{3} = 24.3 cm/sec$$

Alternately, youth could substitute all the known values ahead of time, and solve the equation for the only remaining variable.

b. Compare this value to the actual measured speed. How accurate was this prediction?

Youth predictions should be fairly accurate. For reference, % error is calculated as: $\frac{|theoretical\ \ measurement - actual\ \ measurement|}{theoretical\ \ measurement} \times 100\%$.

In our sample data, 24.3cm/sec predicted is reasonably close to the 26.0cm/sec measured. The % error is 7.0% (if you assume that the 24.3 was theoretically correct), which is very good.

22. Did the presence of an idler gear affect your robot's speed?

Idler gears change direction only, never the gear ratio or the robots speed. This is supported by the fact that the measurements for the idler gear condition can still be predicted from the non-idler gear conditions.

23. Suppose you have a robot with a 40-tooth gear on the motor, and an 8-tooth gear on the wheel.

a. What would its gear ratio be?

$$\frac{\#\ of\ \ teeth\ on\ driven\ gear}{\#\ of\ \ teeth\ on\ driving\ \ gear} = \frac{\#\ of\ \ teeth\ on\ "wheel"\ gear}{\#\ of\ \ teeth\ on\ "motor"\ gear} = \frac{8}{40} = 1/5$$

b. What would its average speed be?

$$\frac{72.8cm/sec\ (condition\ 1\ speed)}{\frac{1}{5}} = 364cm/sec$$

c. Would either of these values change if you added an idler gear? Would anything else change?

Neither would change, because idler gears do not affect speed, only direction. It would go backwards, however.

24. Explain how gear ratio affects the speed of the robot.

Qualitatively: A higher gear ratio will make the robot slower, while a lower gear ratio will make the robot faster.

Quantitatively: Speed increase is proportional to gear ratio decrease, and vice versa.

25. Describe a method for calculating the speed of the robot.

Answers will vary significantly here. The most straightforward way is to find the distance the robot travels in a set amount of time using the desired configuration, and divide distance by time to get speed. Another way is to start with a 1:1 gear ratio and its measured speed, and **divide the 1:1 speed by the new robot's gear ratio** to get the theoretical speed of the robot.

26. Did your result support or refute the hypothesis? Explain.
Hypothesis: "As the gear ratio between the motor and the wheel increases, speed will decrease proportionally."

The result does indeed support the hypothesis, as the increasing gear ratio did cause speed to decrease.

Activity 7 – Tighten Your Belts

Note to the helper

In this investigation, youth learn that belts behave just like spur gears; they have "gear ratios." This is the ratio of the diameter of the output pulley to the diameter of the input pulley. There are some major differences, however, between belts and pulleys and gears. The first difference is the direction of rotation. With a pair of spur gears, the input axle and the output axle rotate in opposite directions; with a belt and pulley, both the input and output axles rotate in the same direction. Youth will also learn that the second major difference is belts cannot transfer as much force as gears. The pulleys move because of the friction between the belt and the pulley. If the output axle were to get stuck, then there would be too much force for the belt friction to overcome, and the belt would slip. You should use a belt and pulley instead of a gear if there is a chance that the output axle, like the robot's wheels, might get stuck. This will keep the motor from locking up and failing.

This unit includes a worksheet where youth capture data and write conclusions. On the following pages you will find the answer key for the worksheet.

Red = exact answers
Magenta = sample

“Belts” Worksheet

Condition	Size of Pulley on Motor (cm)	Size of Pulley on Wheel (cm)	Gear Ratio between Motor Axle and Wheel Axle	Number of Motor Axle Rotations	Distance Robot Traveled (cm) [3 Trials]	Overall Average Distance for Condition (cm)
1	.6	3.5	35/6	100	1. 18.1 2. 18.3 3. 18.1	18.2
2	.6	2.3	23/6	100	1. 26.3 2. 26.6 3. 26.1	26.3
3	2.3	2.3	1	100	1. 84.0 2. 84.1 3. 84.0	84.0

Condition 1:

1. We intend to show a connection between distance and gear ratio, but we are using pulleys, not gears. We can find the gear ratio of different gears by counting their teeth. How can we find the gear ratio of pulleys?

   With pulleys, you can find gear ratio by comparing diameters. The gear ratio of a belt-and-pulley drive is: $Gear\ Ratio = \frac{Diameter\ of\ Driven\ Pulley}{Diameter\ of\ Driving\ Pulley}$

2. Fill in the following values in your data table.
   a. Diameter of the “motor” pulley for this condition
   b. Diameter of the “wheel” pulley for this condition

   These are directly measured. Note that ideally, you should measure the inner part of the groove in the pulley (where the belt will actually run), but this is difficult to do unless you have calipers or another similar tool. If you do not have a suitable measuring device available, you can measure the outer diameter of the pulleys using a ruler or measuring tape, and subtract the approximate depth of the groove: about .1cm for the half-bushing pulley and medium pulley wheel, and .2cm for the deeper large pulley wheel.

c. Gear ratio for this condition

Gear ratio is calculated with pulleys by taking the fraction:

$$Gear\ Ratio = \frac{Diameter\ of\ Driven\ Pulley}{Diameter\ of\ Driving\ Pulley}$$

d. Number of clicks the robot travels.

This is 100 in all conditions, set by the program.

3. If the driving axle goes around once, how many times does the driven axle go around?

Note that gear ratio is defined as the number of times the driving axle must go around in order to make the driven axle turn once. That means that if the driving axle goes around once, the driven axle will make the proportional fraction of the whole turn. The number of turns times the amount per turn will come out to 1 full turn, so we can write:

$$Gear\ Ratio \times Fraction\ of\ Turn = 1\ Full\ Turn$$

$$Fraction\ of\ Turn = \frac{1}{Gear\ Ratio}$$

This makes sense: if it takes 4 turns to go around, you must turn 1/4 of the way around each time. With the diameter measurements in our sample data, that means that the driven axle goes 6/35ths of the way around in one rotation of the driving axle.

4. How far did the robot travel on average in this Condition? Record your answer in the data table.

The average distance is the average of the three individual distances for this condition.

(18.1cm + 18.3cm + 18.1cm) / 3 = 18.2cm

Condition 2:

5-7. See #2-4.

8. Complete the following calculations:
   a. Write a fraction comparing the distance the robot traveled in Condition 1 to the distance the robot traveled in Condition 2.

   This can be a simple improper fraction relating the two quantities, as it most likely will not come out to a very nice number. With our sample data, it would be $\frac{18.2}{26.3}$.

b. Convert your answer to a decimal number.

Again, this will likely not be a nice number. The sample data fraction becomes .69.

c. Round the decimal to the nearest whole number.

.69 from the sample data rounds to 1. Since classroom measurements should not be too far from this amount, they should round to 1 as well.

9. How many times greater distance was traveled in Condition 2 than in Condition 1? Give your answer as a decimal.

Dividing the distance in Condition 2 by the distance in Condition 1 gives the ratio 26.3/18.2 in our sample data, which is 1.44 times as far.

10. Answer the following questions:

a. What is the ratio of the distance traveled by the robot in Condition 1 to the distance traveled by the robot in Condition 2?

Straightforward question in preparation for part c of this question. The answer based on our sample data is $\frac{18.2}{26.3}$.

b. What is the ratio of the gear ratio in Condition 1 to the gear ratio in Condition 2?

Straightforward question in preparation for part c of this question. The answer based on our sample data is $\frac{35}{23}$ (the denominators of the two fractions are the same and cancel out).

c. How are distance traveled and gear ratio related based on these comparisons?

There are many ways to express the same mathematical relationship, and some teachers may wish to forego the specific numeric relationship in favor of the qualitative relationship.

Qualitatively, distance goes up as gear ratio goes down, and goes down as gear ratio goes up.

Quantitatively,

$Distance\ Traveled = \frac{1}{Gear\ Ratio} \times distance\ with\ 1:1\ gear\ ratio$, which is a relationship called by many names, including “inversely proportional”, “proportional to the reciprocal”, and “one over X”. Essentially, it means that if you multiply the gear ratio by some number, the distance traveled will be effectively divided by the same number, and vice versa.

Condition 3:

11-13. See #2-4.

Analysis and Conclusions:

14. In which experimental condition did the robot go the longest distance? The shortest distance?

    Condition 3 goes the farthest; Condition 1 goes the least far.

15. Predict the distance that should have been traveled in Condition 2 based on its gear ratio and the gear ratio and distance traveled in Condition 1.

    This is an interpolation/data verification question, asking youth to make a prediction based on data they have, and check it against an actual measurement they already have. This sort of calculation is often performed by scientists in order to prove the reliability of their experimental methods.

    The gear ratio in Condition 2 is (23/35) times the gear ratio in Condition 1, so the distance in Condition 2 should be (35/23) times as much as in Condition 1. Based on sample data:

$$Prediction = 18.2cm \times \frac{35}{23} = 27.7cm$$

Algebra

The exact method by which we derive this relationship can be solved by beginning with a simple equality that expresses what the theoretical (and observed) relationship between 2 different robots with different gear ratios.

We start with the equation:

$$(Condition\ 1\ Distance) \times (Condition\ 1\ Gear\ Ratio) = (Condition\ 2\ Distance) \times (Condition\ 2\ Gear\ Ratio)$$

We then solve for Condition 2 Distance in the equation.

$$Condition\ 2\ Distance = Condition\ 1\ Distance \times \frac{Condition\ 1\ Gear\ Ratio}{Condition\ 2\ Gear\ Ratio}$$

And finally, we plug in numbers to solve the equation.

$$Condition\ 2\ Distance = Condition\ 1\ Distance \times \frac{Condition\ 1\ Gear\ Ratio}{Condition\ 2\ Gear\ Ratio} = 18.2cm \times \frac{\frac{35}{6}}{\frac{23}{6}} = 27.7cm$$

Alternately, youth could substitute all the known values ahead of time, and solve the equation for the only remaining value.

16. Compare this value to the actual distance traveled in Condition 2. How accurate was the prediction? Give your answer as a percentage of the distance traveled in Condition 1 that the prediction was off by.

This is a percent error calculation. The difference between the predicted and actual values in the sample data is 27.7 – 26.3 = 1.4cm, which in turn is 1.4 / 26.3 * 100% = 5.3% error.

17. Predict what the gear ratio should have been in Condition 3 based on the distance it traveled and the gear ratio and distance traveled in Condition 1.

This uses the same equation we've been observing, but in reverse. The robot in condition 3 went 84/18.2 times as far as Condition 1, so the gear ratio should be 18.2/84 times the gear ratio in Condition 1. Based on sample data:

$$Prediction = \frac{35}{6} \times \frac{18.2}{84} = 1.26:1$$

18. Compare this value to the actual gear ratio in Condition 3. How accurate was the prediction? Give your answer as a percent of the gear ratio of Condition 1 that the prediction was off by.

This is a percent error calculation. The difference between the predicted and actual values in the sample data is 1.26 - 1 = .26, which in turn is .26 / 1 * 100% = 26% error. This appears to be a rather large error value, but is not unusual in this case because of the highly variable nature of friction belts and the placement of the pulleys in this condition.

Several key characteristics of the belt were changed implicitly along with the pulley diameter ratios: the amount that the belt had to stretch, for instance, changed, and with it, a host of other physical properties that directly affect the transmission of power from motor to wheel. These little changes all qualify as sources of systematic error, and would be good candidates for examination in future applications.

Further, the arrangement of the pulleys in this condition puts them so close together that it introduces the possibility that pulleys will actually rub against each other, causing additional error.

19. Explain how gear ratio affects the distance a vehicle will travel when the number of driving axle rotations is held constant.

Qualitatively: A higher gear ratio will make the robot go a shorter distance, while a lower gear ratio will make the robot go farther.

Quantitatively: Distance increase is proportional to gear ratio decrease, and vice versa.

20. Did your results support or refute the hypothesis? Explain.
Hypothesis: As the gear ratio between the motor and the wheel on Tankbot decreases, the distance it travels will increase proportionally.

The results support the hypothesis, with some error. As gear ratio decreased, distance increased mostly proportionally.

Activity 8 – Do the Time

Note to the helper
In this investigation youth will learn about the inversely proportional relationship between gears and speed when distance is a constant. As the gear ratio increases, the speed of the robot decreases. Youth will use a light sensor to accurately control and measure when the robot stops. The light sensor will be focused on the ground; when the light sensor sees the end line it will stop and record the amount of time it took to travel that distance. Youth will record the time, change the gear ratio on the drive train, and run the experiment again. At the end of the investigation, youth should see a mathematical relationship between distance traveled, time, and gear ratio.

<u>"Gears and Speed – Constant Distance" Answer Key</u>

Red = exact answers
Magenta = sample

Condition	Number Of Teeth On Gear On Motor	Number Of Teeth On Gear On Rear Axle	Gear Ratio (Rear Axle To Motor)	Distance Tankbot Traveled (cm)	Length Of Time The Robot Moves (sec) [3 Trials]	Average Speed For Each Trial (cm/sec)	Overall Average Speed For Condition (cm/sec)
1	24	24	1:1	200	1. 3.0	1. 66.7	67.4
					2. 2.9	2. 69.0	
					3. 3.0	3. 66.7	
2	8	40	5:1	200	1. 12.2	1. 16.4	16.3
					2. 12.3	2. 16.3	
					3. 12.3	3. 16.3	
3	8	24	3:1	200	1. 7.5	1. 26.7	26.4
					2. 7.6	2. 26.3	
					3. 7.6	3. 26.3	

Condition 1:

1. Answer the following questions:
   a. Will your robot run for exactly 200 cm if you follow the preceding instructions?

Why or why not?

Typically, the robot will not run exactly 200 cm for a variety of reasons. For instance, robots will roll a little past the tape line even after the stop command has been issued by the program. There is also a certain amount of human error in setting up and aiming the robot.

b. The number displayed on the RCX indicates the amount of time to go what distance?

The number on the RCX is the amount of time to travel from tape to tape, because the program stops counting as soon as it sees the second line. This means that it is effectively 200 cm, and disregards any distance past the line that the robot rolls.

c. When you calculate the speed for this condition, should you use the distance the robot eventually traveled, or should you use 200 cm?

You should use 200 cm so that the distance traveled corresponds to point the time was recorded.

2. Fill in the following values in your data table.
   a. Number of teeth on the "motor" gear for this condition
   b. Number of teeth on the "wheel" gear for this condition

These are direct observation by counting the number of teeth on the gears.

c. Gear ratio for this condition

Gear ratio is calculated for toothed gears by taking the fraction:

$$\frac{\#\ of\ teeth\ on\ driven\ gear}{\#\ of\ teeth\ on\ driving\ gear} = \frac{\#\ of\ teeth\ on\ "wheel"\ gear}{\#\ of\ teeth\ on\ "motor"\ gear} = \frac{24}{24} = 1$$

d. Distance the robot ran in this condition

As discussed in Problem 1, this should be 200cm for all conditions regardless of how far the robot may have drifted after the motors were powered down.

3. Calculate the average speed for each trial in this condition, and fill out the appropriate column in the data table.

Average speeds are calculated by taking the distance traveled for each trial in the condition, and dividing by the amount of time it took to travel that far. There should be one average speed for each of the 3 trials in this condition.

200cm / 3.0sec = 66.7cm/sec
200cm / 2.9sec = 69.0cm/sec

200cm / 3.0sec = 66.7cm/sec

4. Calculate the overall average speed by averaging the speeds from each of the three individual trials. Fill out the appropriate cell in the data table.

   The overall average speed is the average of the three calculated speeds. Its purpose is to give you a number that has less random variance in it than the individual measurements.

   (66.7 + 69.0 + 66.7) / 3 = 67.4cm/sec

5. Answer the following questions:
   a. How many times does the gear on the motor have to turn for the wheel to make one full rotation?

      The motor gear turns once per turn of the wheel gear. You can find this either by direct observation, or by calculation based on the gear ratio.

   b. How is this number related to the gear ratio for this condition?

      The number of motor gear turns per wheel gear turn is the same as the gear ratio by definition. Observationally, youth should still be able to see that they are the same.

Condition 2:

6-9: See #2-5

9a. How many times does the gear on the motor have to turn for the wheel to make one full rotation?

The motor gear turns five times per turn of the wheel gear.

Condition 3:

10. What happened? What change did we make to the robot that caused this change in behaviors?

    Adding an idler gear into the robot's gear train causes a reversal in the direction of rotation, which is observable as the robot moving backwards rather than forward.

11. What would happen if we added a second idler gear between the 40-tooth gear and the 24-tooth gear?

    Adding another idler gear would cancel the effect of the first one, because it would “double-reverse”, i.e. the two reversals would negate each other.

12. What happens when you reverse the polarity on a motor? How does this help with our problem?

Reversing the polarity on a motor reverses its direction, just like adding an idler gear. By having both an idler gear and a polarity reversal, we have effectively reversed twice, and the two cancel each other out.

13-16. See #2-#5.

Analysis and Conclusions:

17. In which experimental condition did your robot move fastest?

    The robot with the lowest gear ratio, the 1:1 gear ratio in Condition 1, should be fastest by a large margin.

18. In which experimental condition did your robot move slowest?

    The robot with the highest gear ratio, the 5:1 gear ratio in Condition 2, should be slowest by a clear margin.

19. Answer the following questions:
    a. Write a fraction comparing the speed in Condition 3 to the speed in Condition 2.

       Youth should come up with a fraction close to 5/3 if their data was good.

    b. Convert your answer to a decimal number.

       Straight decimal conversion of the fraction from part a, or approximately 1.66

    c. Round the decimal to the nearest whole number.

       Straight whole number rounding of the decimal from part b. or 2

20. Answer the following conditions:
    a. What is the ratio of speeds between the robot in Condition 1 and the robot in Condition 2?

       5:1 theoretical, about 4.13:1 measured

    b. What is the ratio of gear ratios between the two robots?

       (Gear ratio of Condition 1 / Gear ratio of Condition 2) = 1:5

    c. How are speed and gear ratio related, based on this comparison?

       There are many ways to express the same mathematical relationship, and some teachers may wish to forego the specific numeric relationship in favor of the qualitative relationship.

Qualitatively, speed goes up as gear ratio goes down, or as the gear ratio goes up, the speed goes down.

Quantitatively, $Speed = \frac{1}{Gear\ Ratio} \times speed\ with\ 1:1\ gear\ ratio$, which is a relationship called by many names, including "inversely proportional", "proportional to the reciprocal", and "one over X". Essentially, it means that if you multiply the gear ratio by some number, the speed will be effectively divided by the same number, and vice versa.

21. Answer the following conditions:

a. Predict the speed of the robot in Condition 3 based on its gear ratio and the speed you measured for Condition 1.

This is an interpolation/data verification question, asking youth to make a prediction based on data they have, and check it against an actual measurement they already have. This sort of calculation is often performed by scientists in order to prove the reliability of their experimental methods.

The gear ratio in Condition 3 is 3 times the gear ratio in Condition 1, so the speed in Condition 3 should be 1/3 times as much as in Condition 1. Based on sample data:

$$Prediction = 67.4cm/sec \times 1/3 = 22.5cm/sec$$

Algebra

The exact method by which we derive this relationship can be solved by beginning with a simple equality that expresses what the theoretical (and observed) relationship between 2 different robots with different gear ratios.

We start with the equation:

$$(Condition\ 1\ Speed) \times (Condition\ 1\ Gear\ Ratio) =$$
$$(Condition\ 3\ Speed) \times (Condition\ 3\ Gear\ Ratio)$$

We then solve for Condition 3 speed in the equation.

$$Condition\ 3\ Speed = Condition\ 1\ Speed \times \frac{Condition\ 1\ Gear\ Ratio}{Condition\ 3\ Gear\ Ratio}$$

And finally, we plug in numbers to solve the equation.

$$Condition\ 3\ Speed = Condition\ 1\ Speed \times \frac{Condition\ 1\ Gear\ Ratio}{Condition\ 3\ Gear\ Ratio}$$

$$= 67.4cm/sec \times \frac{1}{3}$$

$$= 22.5cm/sec$$

Alternately, youth could substitute all the known values ahead of time, and solve the equation for the only remaining variable.

b. Compare this value to the actual measured speed. How accurate was this prediction?

Youth predictions should be fairly accurate. For reference, % error is calculated as: $\frac{|theoretical\ measurement - actual\ measurement|}{theoretical\ measurement} \times 100\%$.

In our sample data, 22.5cm/sec predicted is reasonably close to the 26.4cm/sec measured. The % error is 17.3% (if you assume that the 22.5 was theoretically correct), which is not bad.

22. Did the presence of an idler gear affect your robot's speed?

Idler gears change direction only, never the gear ratio or the robots speed. This is supported by the fact that the measurements for the idler gear condition can still be predicted from the non-idler gear conditions.

23. Suppose you have a robot with a 40-tooth gear on the motor, and an 8-tooth gear on the wheel.

a. What would its gear ratio be?

$$\frac{\#\ of\ teeth\ on\ driven\ gear}{\#\ of\ teeth\ on\ driving\ gear} = \frac{\#\ of\ teeth\ on\ "wheel"\ gear}{\#\ of\ teeth\ on\ "motor"\ gear} = \frac{8}{40} = 1/5$$

b. What would its average speed be?

$$\frac{67.4cm/sec\ (condition\ 1\ speed)}{\frac{1}{5}} = 337cm/sec$$

c. Would either of these values change if you added an idler gear? Would anything else change?

Neither would change, because idler gears do not affect speed, only direction. It would go backwards, however.

24. Explain how gear ratio affects the speed of the robot.

Qualitatively: A higher gear ratio will make the robot slower, while a lower gear ratio will make the robot faster.

Quantitatively: Speed increase is proportional to gear ratio decrease, and vice versa.

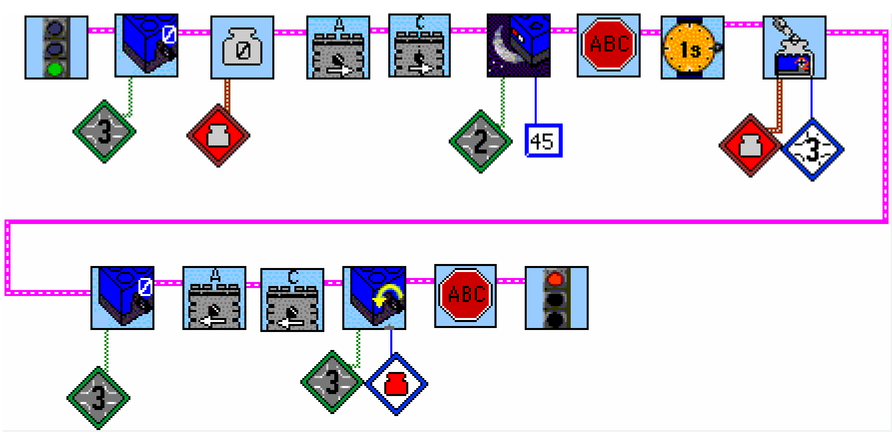
25. Describe a method for calculating the speed of the robot.

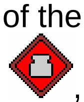
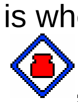
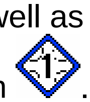
Answers will vary significantly here. The most straightforward way is to find the time the robot takes to travel a set distance using the desired configuration, and divide distance by time to get speed. Another way is to start with a 1:1 gear ratio and its measured speed, and **divide the 1:1 speed by the new robot's gear ratio** to get the theoretical speed of the robot.

26. Did your result support or refute the hypothesis? Explain.
Hypothesis: "As the gear ratio between the motor and the wheel increases, speed will decrease proportionally."

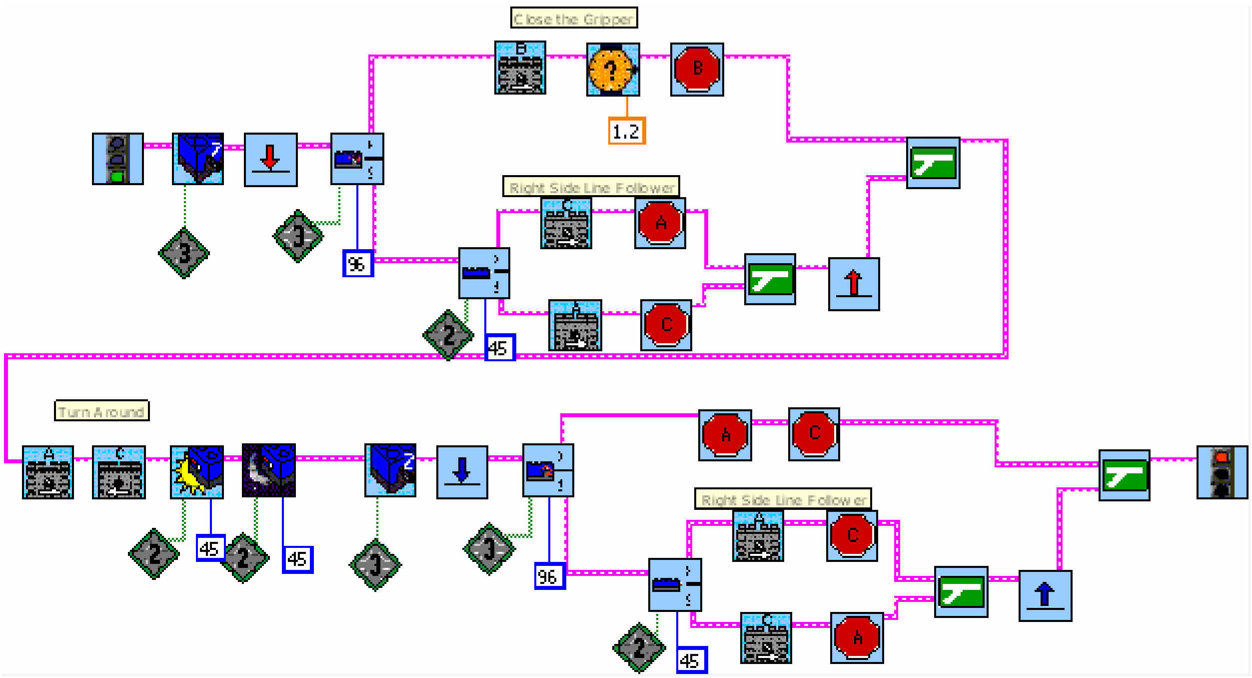
The result does indeed support the hypothesis, as the increasing gear ratio did cause speed to decrease.

Activity 9 – It Varies…



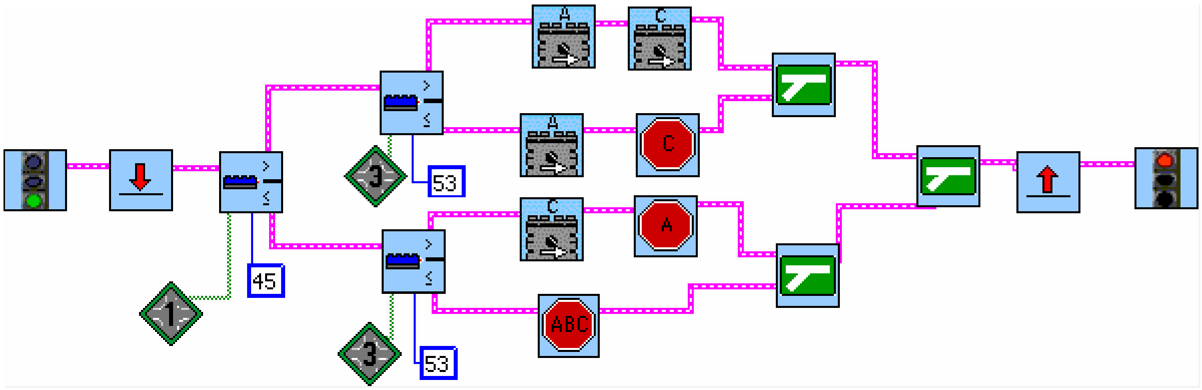
One of the hardest things to learn when using Containers is when to use the Container icon, , as opposed to the Value of the Container icon, , as well as when to use the Port Modifier icon, , as opposed to the Value of the Port icon . Experience will make it easier for you to distinguish which icons to use, but in the mean time you should know that Robolab won't allow you to connect up the wrong modifier. If you're trying to connect the Container icon and Robolab won't let you connect it, use the Value of the Container icon and watch how easily it connects.

Activity 10 – Grips and Grabs



In going out to get the can of soda, the robot follows the right side of the line. In coming back with the can, it follows the left side of the line. Take a look at the area in the program marked 'Turn Around'. The robot was following the right side of the line and now it's turning to the right in order to find the line so it can follow back. If the program said turn until it sees dark, what do you think would happen if it was already over dark (and it is over dark half the time)? If you thought it wouldn't do anything, you're right. By writing the program for the robot to turn until it sees light, first and then sees dark, you'll find the line to come back every time. Here's how: If you start the turn while the robot is over dark, it'll turn until it sees light and then continue to turn until it sees dark. If you start the turn while the robot is over light, when the program says turn until you see light, the robot won't do anything, it'll just move on to the next icon which says continue turning until you see dark.

Activity 11 – Double Duty



In this program, the light sensor on port 1 is on the left and the light sensor on port 3 is on the right. When both sensors see light, you'll want your robot to go straight. When one sensor sees light and the other sensor sees dark, you want your robot to turn toward the line. When following a line, both sensors should never see dark. When they do, there is a problem with your robot and you'll want it to stop. Did you see that the threshold is different for each of the light sensors? You can't take it for granted that the threshold will be the same for both light sensors. You need to go back and calculate the threshold for each sensor.

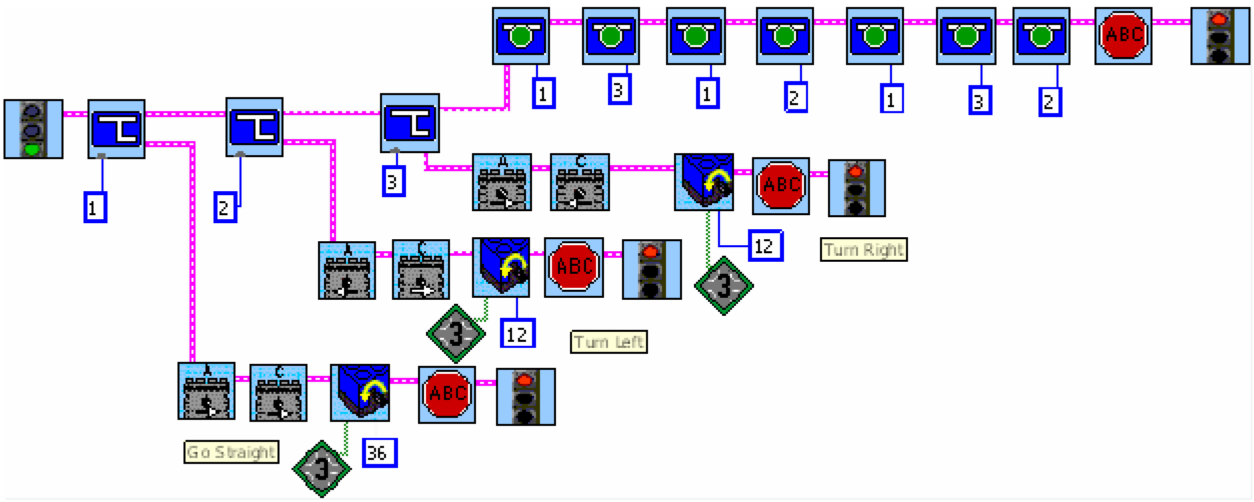
Activity 12 – Keep it Simple, Silly

Pseudocode:

Go straight for a number of clicks
Go right for 90 degrees
Go straight for a number of clicks
Go left for 90 degrees
Go straight for a number of clicks
Turn right for 90 degrees
Go straight for a number of clicks
Turn left for 90 degrees

Your maze may look different, in which case your pseudocode would be different. But, it would still only include the three behaviors, turn right, turn left, and go straight.

Program



Notice that we only wrote three different subroutines: one to go straight, one to go left and one to go right. Then, we just used them as we needed them to follow the maze. The subroutines that you write will look very similar; you may have put your rotational sensor on a different port or it may take a different number of clicks to go straight or turn. The only thing that may be different is the order in which you use the subroutines and that's based entirely upon the design of your maze.

Activity 13 – Beyond Subroutines

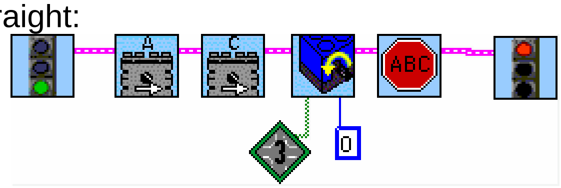
Pseudocode:

Go straight for 30 clicks
Go right for 80 degrees
Go straight for 45 clicks
Go left for 105 degrees
Go straight for 60 clicks
Turn right for 120 degrees
Go straight for 90 clicks
Turn left for 135 degrees

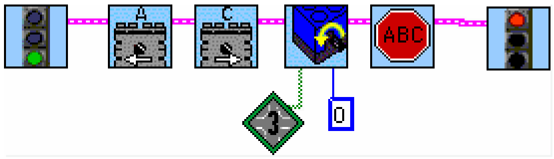
Your maze will almost assuredly be different than this one, but, as in the previous activity, you're still only performing three behaviors, going forward, turning left and turning right.

The three behaviors, in general, will look like this in Robolab:

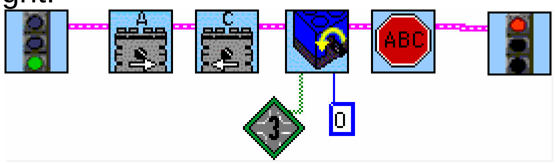
Go straight:



Turn left:

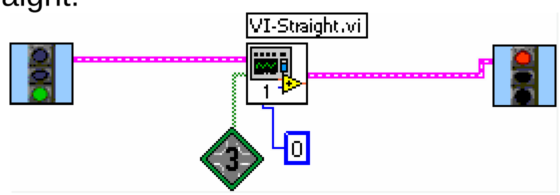


Turn right:



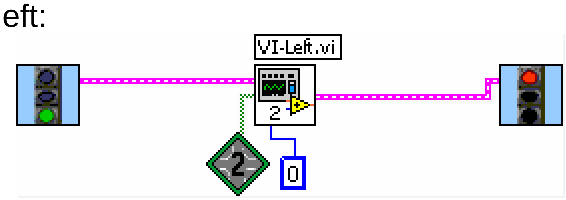
When we convert these to sub-VIs, they look like this:

Go straight:

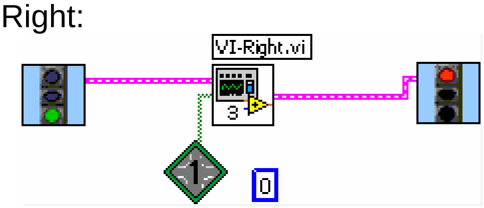


When we saved this, it was called VI-Straight.vi. When you name a sub-VI, it's always best to call it something meaningful, so you'll remember what it is when you go looking for it. It's also good to start the name with the letters, VI, to differentiate the sub-VI from a saved program.

Turn left:



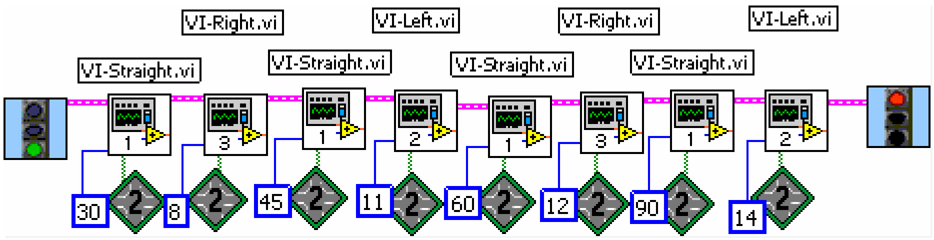
Turn Right:



You may be wondering how the names go to the top of the icon. Its simple and it's a good idea to do it with all the sub-VI icons because they all look alike. When you're in Robolab, if you right-click on the icon, a new menu will come up and at the top of the new menu is the link, Visible Items. Click on "Visible Items" and then click on 'Label' and the title of the icon will appear.

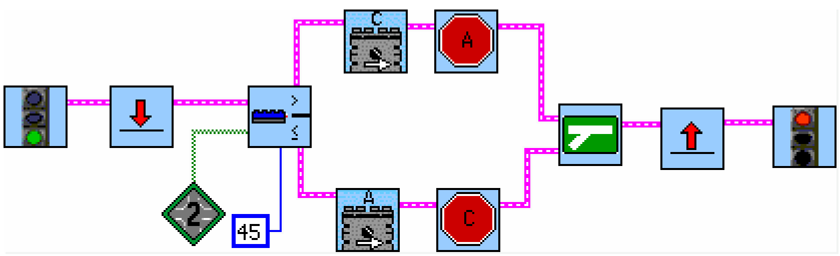
Now that the three sub-VIs have been developed, it's time to write the program. On the Robolab Functions palette, on the right hand side near the bottom, you'll see an icon that looks like a cartoon idea balloon. If you place your mouse over it, you'll see 'Select a VI…' near the top of the Functions palette. When you click on that icon, all your

Robolab programs will come up. But since you started the name of your sub-VIs with the letters, VI, they're all together near the bottom of page. If you drag the sub-VI icons to your block diagram page, your program is almost done. From the pseudocode, above, you can see that you'll need four straight sub-VIs, two left sub-VI's and two right sub-VI's. Drag all the icons on to the block diagram page and put them in the correct order according to the pseudocode, wire them together and add the modifiers (input port number and numeric constant). If your rotational sensor is on input port 2, the program will look like this:

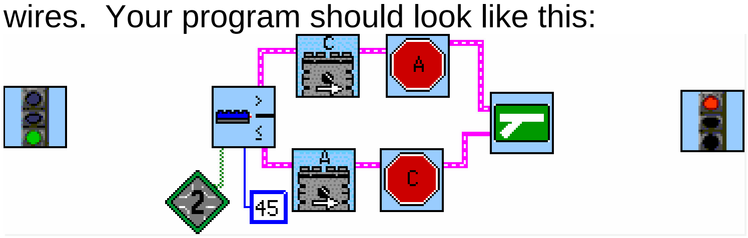


The important thing to remember about the sub-VIs, is that the program not only looks cleaner than one using subroutines does, all of the sub-VIs can be used in other programs. They are yours to use forever.

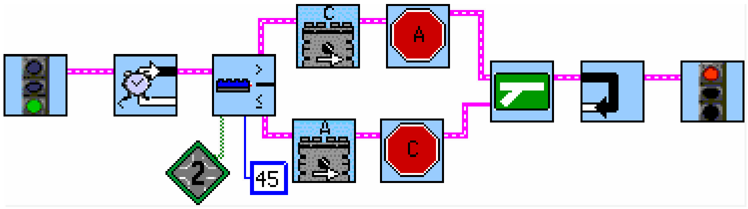
Activity 14 – Loop-D-Loop
This is a copy of the Line Follower you wrote in one of the Explorer activities.



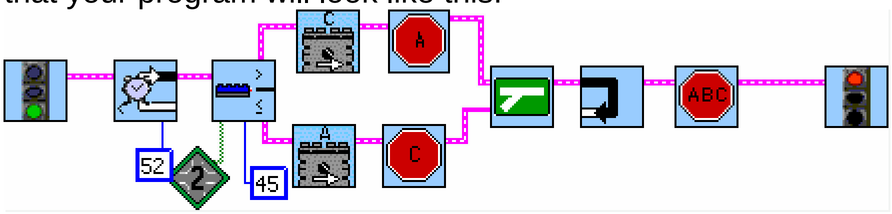
The first thing you'll want to do is delete the red jump and land and get rid of the bad wires. Your program should look like this:



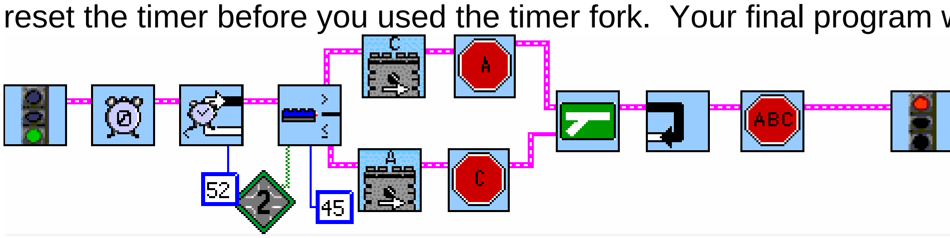
Now, go to the Loops sub-palette and get the Loop While Value of Time is Less Than icon. Place it to the left of the Light Sensor Fork icon and place the End of Loop icon to the right of the Fork merge icon. Wire it up and your program will look like this:



Your going to need a modifier on the Timer icon (remember, it counts in tenths of a second) and a Stop All Outputs icon just before the Red Light icon. Once you've done that your program will look like this:



When you look in the upper left of the Robolab screen you'll see that you have a white arrow. When you click on the white arrow to download your program, you should get an error message: PROGRAMMING ERROR: You must initialize Timer 1 before you have the timer fork. Remember that the timer starts to run the instant that you turn your robot on, so you'll need to reset the timer to zero before you use it, just like you needed to reset the timer before you used the timer fork. Your final program will look like this:



You've now written a timed line follower program, just like you wrote earlier but without the need for a jump and a land. The program will do whatever is in the timer loop for 5.2 seconds and then move on to the next icon (Stop all Outputs). Can you modify this program so that you don't even need the Light Sensor Fork?