Gear Ratio Activity

STEM Lesson for TI-Nspire™ Technology

Objective: Students will collect data and analyze data using graphs. Students will also investigate the meaning of the *x* and *y* values of a quadratic curve derived from a quadratic regression on real-world data. Students will then use the graphs to decide which gear ratio is the best.

About the Lesson: Tracks on which Sprint Cup Series races occur vary in length, banking and surface among other things. On all tracks, proper set up to handle the turns is critical to team success but this is especially true for short tracks. For example, in Bristol the cars are almost never at top speed but are either accelerating or breaking around the short 0.533 mile track. During testing, NASCAR teams use data collection systems and technology to gather data on how the car performs with various setups. During a race however, the driver is the only way for a race team to collect data on how the car performs, so some drivers have learned to break a turn down into 16 points so he or she can communicate how the car feels along the turn. For both NASCAR and T80 SRC drivers, as a driver negotiates a turn, the car decelerates as it enters the corner then accelerates back up to top speed when it exits the turn. How fast your car can accelerate and how fast your car can go on the straight-aways are greatly dictated by the gear set. To NASCAR teams, it is almost a no-brainer that they'll install the right set because that decision rarely changes for a particular track. T80 SRC teams need also need to understand how gears impact performance and will model that in this investigation. For three different gear sets, gather data on how long it takes to drive (or use data provided) short, medium, and long straight-aways. Graph drive time as a function of gear ratio (ratio of spur gear teeth to pinion gear teeth) for each track (as a different series) to find the best gear ratio for each one. Given a table of available gears, choose the best set for the race. If you have Ten80 SRC cars, test your prediction.

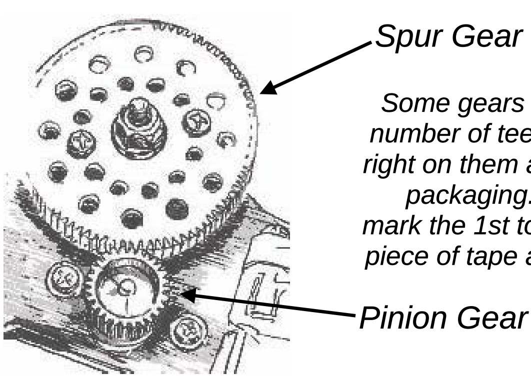
Materials: RC car
3 drag strips: 50, 75, and 100 ft
At least 3 different sets of spur and pinion gears and tools to install
Stop watches (Number depends on the number of students in the group)
Student Worksheets

Procedure:

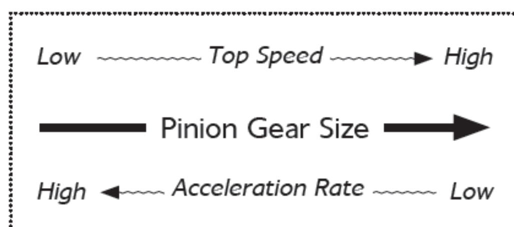
1. With a fully charged battery. Set the car at the start line and decide what the "GO" signal will be.
2. Record the pinion and spur gear sizes installed in the car.
3. Make sure all time keepers are ready and have another student give the "GO" signal. Make sure all time keepers can see the start and finish line clearly.
4. Drive from the start line to the finish line on the 50 ft track. Time keepers measure the time it takes to drive the drag strip while the driver drives.
5. Record lap number and each measured drive time. Drive the track repeatedly until times are consistently fast, at least three laps that are within 0.5 seconds of each other.
6. Change the pinion gear to a bigger one and repeat steps 2-5.
7. Change the pinion gear to a smaller one than the original one and repeat steps 2-5.
8. Repeat steps 1-7 for the 75- and 100-ft tracks.

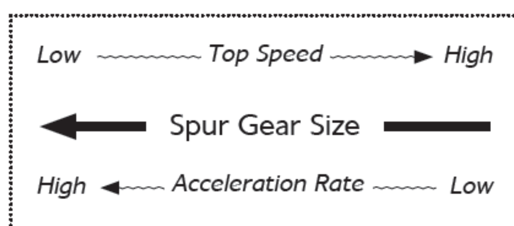
Analysis:

In a NASCAR car, the engine is attached to a transmission which has a set of four gears. The drivers use the first three gears to get up to speed from pit lane or a restart then they use only fourth gear while they are lapping at speed. Typically fourth gear has a 1:1 ratio which means that there is no torque multiplication. However, the transmission is connected to a gear at the back of the car, which depending on the track can be as low as 3.2:1 to as high 6.5:1. In a radio controlled car there are only two gears, one on the motor and one attached to the rest of the drive train. The picture shows the gear arrangement in the Ten80 SRC cars.



Some gears have the number of teeth printed right on them and on the packaging. If not, mark the 1st tooth with a piece of tape and count.





The gear ratio is calculated by dividing the number of teeth on the spur gear by the number of teeth on the pinion gear:

$$\text{Gear Ratio} = \frac{\text{Number of Teeth on Spur Gear}}{\text{Number of Teeth on Pinion Gear}}$$

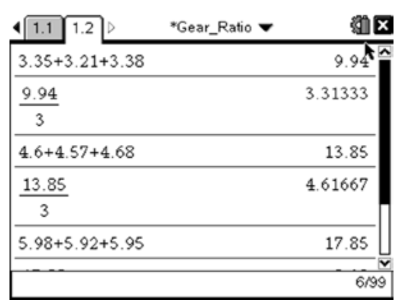
If the gear ratio is 3:1, it means that the motor has to turn 3 times to get the spur gear to move one rotation. The bigger the gear ratio the slower the top speed of the car will be, but there will be more torque available to move the car. If the gear ratio is too low, the motor will not have enough power to get the car moving.

1. Determine the gear ratio for your data.

2. If the motor in an RC car is moving at 12,000 RPM (rotations per minute), how fast is the spur gear turning?

3. On your handheld, go to My Documents and open the file named *Gear_Ratios.tns.*

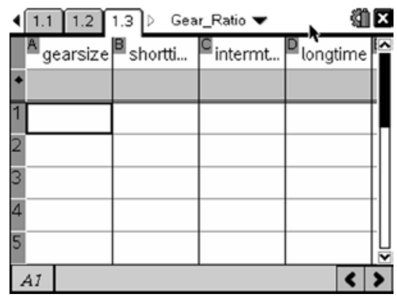
4. Use ctrl ▶ to move to page **1.2**. Choose the 3 most consistent times for each track and calculate the average drive time for each gear set at each straightaway length.



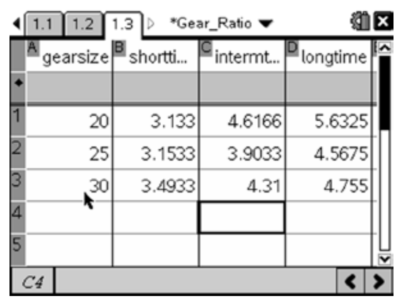
5. Fill in the table below with the average drive times.

PINION GEAR SIZE (teeth)	SHORT TRACK (50 FT)	INTERMEDIATE TRACK (75 FT)	LONG TRACK (100 FT)

6. Use (ctrl) ▸ to move to page **1.3**. In the top row type titles for your columns. Use the ▴▾▸◂ keys to move around the table. The first column should be the gear size and the next 3 columns will be the drive times for each straightaway length.



7. Enter the data into the table starting in row 1 of column **A**. Type the number and then press (enter) or ▾ to move to the next cell.

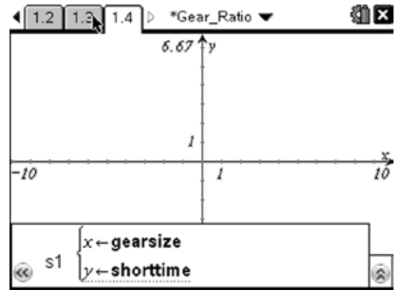


Now we want to use scatter plots and regression lines for each gear size and time. This will allow us to analyze the data and decide which gear set works best for which straightaway length.

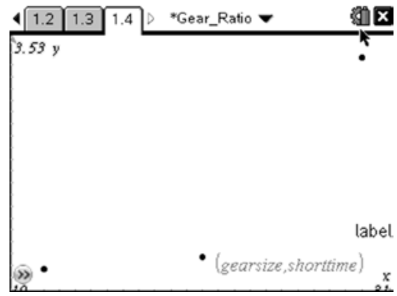
8. Which variable is the independent variable *x*?

9. Which variable is the dependent variable *y*?

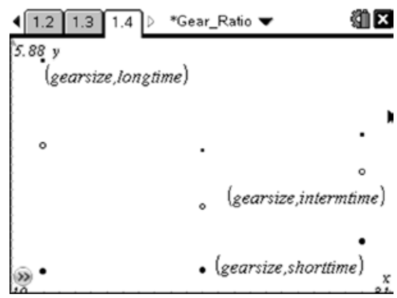
10. Move to page **1.4**. Graph the scatter plot of average drive time vs. gear ratio. To do this first make sure the cursor is in the function bar. Press (var) and choose your title for gear size. Press ▼ then (var) and choose your variable for the short track time.



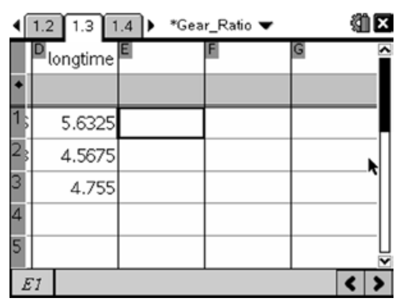
11. Press (enter). Now adjust your window to view the data by pressing (menu) then choosing **Window/Zoom > Zoom – Data**. An example of a set of data is shown at the right.



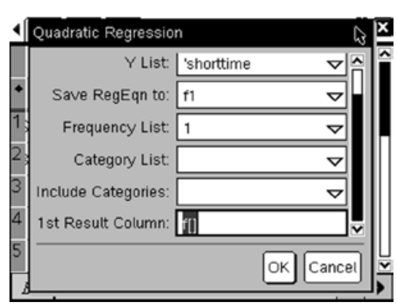
12. Press (tab) to bring the function bar back and repeat steps 10 and 11 for the intermediate and long tracks. You can move the labels by hovering over the label then pressing (ctrl) then (grab) to grab then the touchpad to move if needed. An example set of data is shown at the right. Notice each data set has a different symbol for the points.



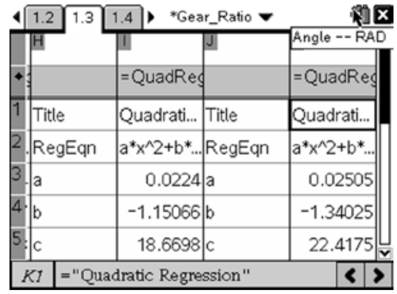
13. Now we want to use regression analysis to derive curves for each set of data. Move back to page **1.3** and move to column **E**.



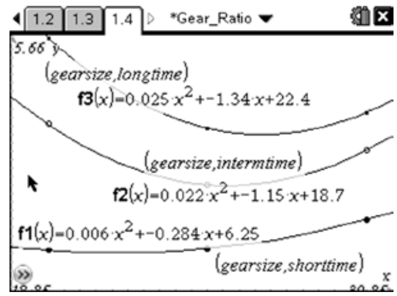
14. Press (menu) then choose **Statistics > Stat Calculations > Quadratic Regression**. The regression template will pop up. Remember to press (tab) to switch boxes. Click the arrow at the right of each box to access the drop down menus. Choose *gearsize* from the drop down menu for the X List and *shorttime* for the Y list. Tab through the other options until you get to 1st Result Column. Click beside the letter and change it to 'f' if it isn't already. Click OK.



15. Repeat the process for the intermediate and long tracks.

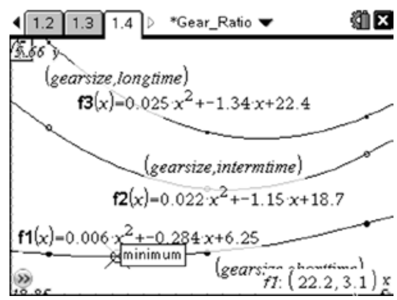


16. Move to page **1.4** and graph the regression curve. Press (menu) then choose **Graph Type > Function**. Press ▲ to see your function in f1 then press (enter). You should see your line on top of your data points. Repeat for f2 and f3. Move the labels around the screen as needed to see everything clearly.



Since our goal is to achieve the lowest lap time possible, we look at the minimums of the curves. For the 50-foot data the minimum occurs at a pinion gear slightly below the 25-tooth run of the data provided. Note how the optimum pinion gear size gets bigger as the course length increases.

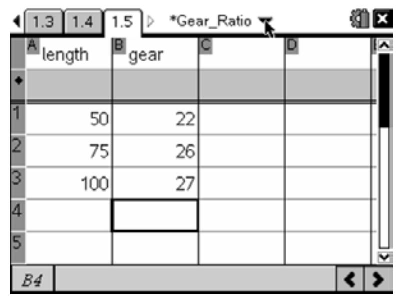
17. Find the exact x-value of the minimum for each curve by tracing. Press **Menu > Trace > Graph Trace**. The cursor will show up on one of the curves. Use the ◀ and ▶ keys to move along a curve and the ▼ and ▲ keys to switch curves. The word "minimum" will pop up when you are there. In the bottom right corner, the coordinates will appear as you trace.



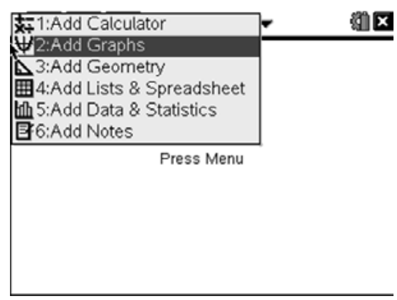
18. Remember the x-value is the gear size, but real-world gears can only be bought to the whole tooth. What is the optimum gear size for each size track?

19. Now estimate the lap time a driver should get based on your gear choice by tracing the curve to the whole number gear sizes and record it below.

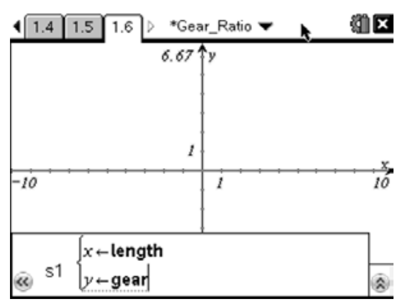
Sometimes crew chiefs have to set up the car for a straightaway length that they haven't had the chance to test and gather data for yet. We can use the data we have collected to predict what gear set the track should need. Of course there are always adjustments the crews have to make after running a few laps, but at least they can get a good starting point.



20. Move to page **1.5**. Create titles and input your straightaway length and best gear size data from questions 18 and 19. Remember you cannot use the same titles as before because the Nspire remembers all column titles as variables and the data in the column as the assigned values.

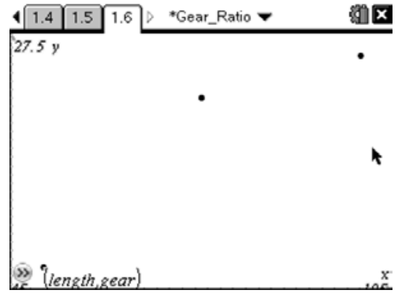


21. Graph the data as a scatter plot of gear size vs. straightaway length. Press (ctrl) then (doc▾) to add a page in the current document. Next click **2:Add Graphs** using the touchpad or choose it by pressing ▼ then (click).



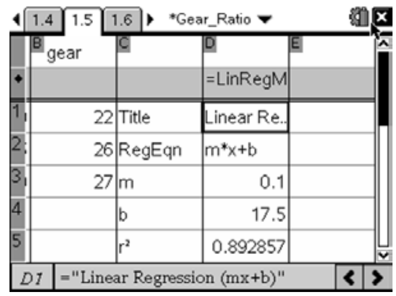
22. Press (menu) then **Graph Type > Scatter Plot** to set up the graph. Press (var) and choose your title for the length as the independent variable *x*. Press ▼ then (var) and choose your title for the optimum gear size.

23. Press (enter) and zoom to the data by pressing (menu) then choosing **Window/Zoom > Zoom – Data**.

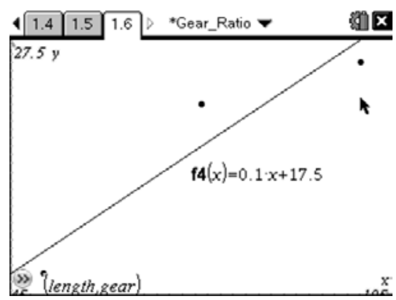


24. Move back to page **1.5** to do a linear regression on the data to derive a function that will predict a pinion gear size for any straightaway length.

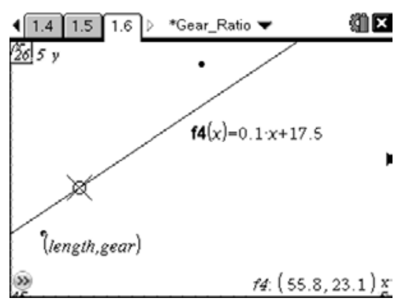
25. Press (menu) then choose **Statistics > Stat Calculations > Linear Regression (mx+b)**. The regression template will pop up. Remember to press (tab) to switch boxes. Click the arrow at the right of each box to access the drop down menus. Choose *length* from the drop down menu for the X List and *gear* for the Y list. Tab through the other options until you get to 1st Result Column. Click beside the letter and change it to 'c' if it isn't already. Click OK.



26. Move back to page **1.6** and graph the regression line. Press (menu) then choose **Graph Type > Function**. Press ▲ to see your function in f4 then press (enter).

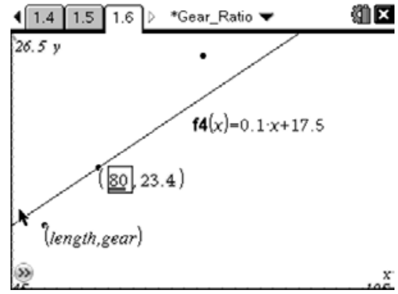


27. Press **Menu > Trace > Graph Trace** to trace the function and see an estimated gear size for each length in the bottom right corner.



28. Trace the function until you get to *x* = 60 (a straightaway length of 60 ft). What is the recommended pinion gear size (*y* value rounded to whole number)?

29. You can also go straight to a certain length by setting a point on the line. While in tracing, press [key] to create a moveable point on the line. This point should show coordinates when you set it. Next press (esc) and click on the *x*-coordinate twice. A cursor will pop up and a box will form around the number you are editing. Just press (del) and type the length you need.



30. Recommend pinion gear sizes for the following straightaway lengths.

70 ft –

80 ft –

95 ft –

31. If you have a previous crew chief's data recommending a 90 tooth spur gear and a 26 pinion gear for an 80-ft straightway, what pinion gear would be the best if you only had a 79 tooth spur gear and wanted to achieve the same results?