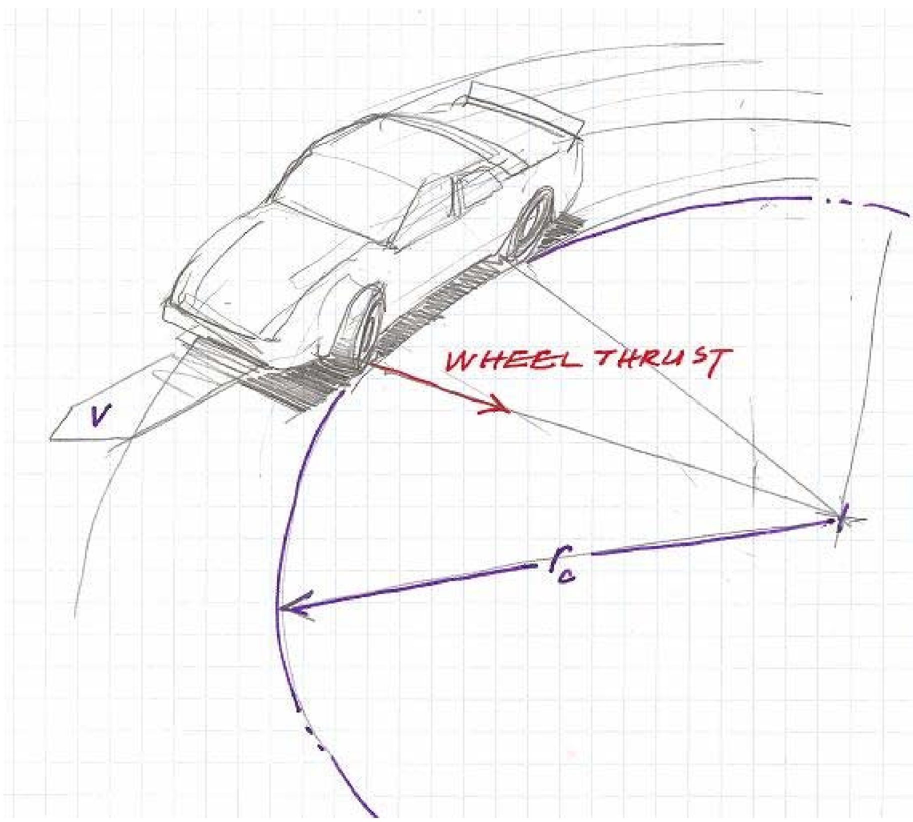
The Science of Racing Series

Activities Created by Ten80 Education
and Texas Instruments



Activity 4: On Balance

The Science of Racing
On Balance

Activity Overview

Stable things last; unstable things crash!

In science your understanding is only as good as your measure.

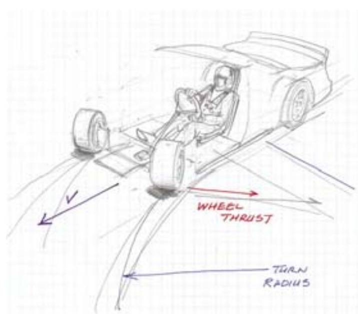
By the time you have arrived to play your first tee-ball baseball game, you've already figured out that the quickest way to run around the bases is not the shortest path.

The shortest path would be to run straight lines between the bases and make hard 90 degree left turns at each base: shortest path but not the quickest. So it is also for race cars, the shortest path around a track is not the quickest.

Any middle school student can explain that in order to follow the shortest path around the bases it would be necessary to dramatically slow down in order to navigate the corner and then speed up to next base. The overall result is that a longer path that follows a larger radius turn is actually the quickest route.

You're limited by turning corners.

Acceleration is a change in either direction or speed. It requires an applied force to accelerate an object. The limit in running the bases is traction between shoes and dirt. In the case of the race car the limit is the friction between the tires and the asphalt.



The force necessary to accelerate an object onto a curved path, in other words to deflect it from a straight line, is defined by Newton's Second Law: $F = m V 2 / r$

F is the required force to accelerate an object having mass, m, traveling at a velocity of V, on a circular path of radius r. If the force that can be applied is limited by traction, then one can either slow down (smaller V) or follow a larger radius path (bigger r).

Activity at a Glance:
Grade: 6-9
Subject: Phys Science
Topic: Motion in a Circle
Time: 2x50-min periods

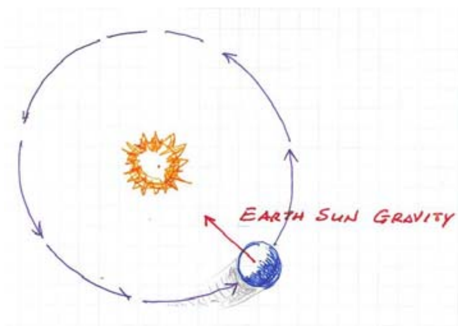
Visit the engineers and educators of Ten80 Education at

www.ten80education.com

Materials:
- TI-73 Explorer
- Student Handout
- Transparencies with sample data: On Balance_4A and 4B
- Background Paper: F=ma Article: Science of Racing

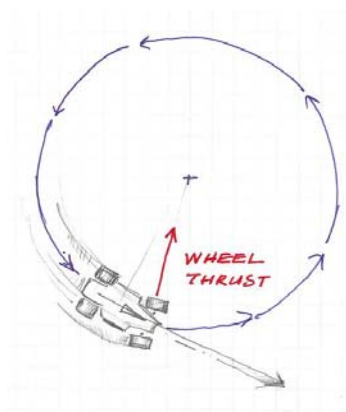
Optional for collecting your own data:
- RC (radio controlled) car (1/16th or smaller is suggested)
- Scale to weigh the RC car
- Stop watches
- Tape measure (meter stick, or yard stick, etc.)

The planets are subject to the same effect. The applied force to deflect the planet away from a straight path and into a near-circular orbit is the gravitational force between the planet and the Sun. The quantity V^2r is the same for all planets, where V is the velocity of the planet and r is the planet-Sun distance. This was first determined by Kepler, circa 1600.

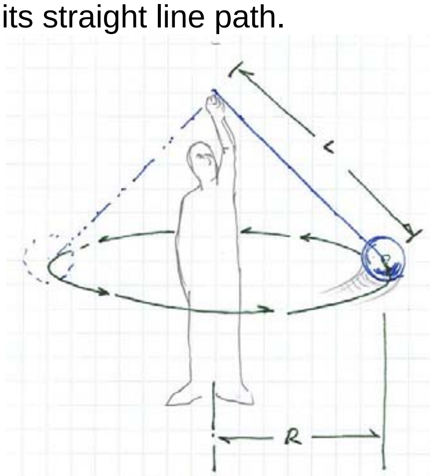


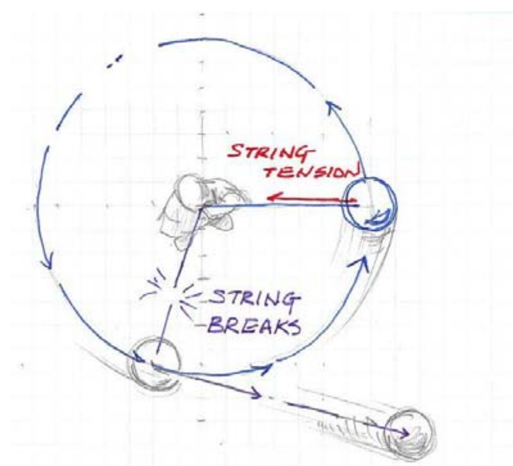
In the case of a car making a turn, the force to deflect the path of the car from a straight line is provided by the steered wheels.

The wheel thrust is produced by the driver turning the steering wheel which is in turn connected to the front wheels of the car. The steered wheels pull the car into the desired turn, the curve.



This same effect can be observed in whirling an object around on a string. The force that is required to pull the object into a curved path is supplied by the string. If the string breaks, or is released, the object continues on its straight line path.





Racing Vocabulary

A car that doesn't turn as well as expected is called "loose" in racing jargon. It "under-steers" in the sense it doesn't rotate as much as expected from the direction of the front wheels.

Loose:

The car over steers, over rotates, spins out.

Tight:

The car pushes, does not turn

Thrust:

To push or drive quickly and forcibly

Drag:

To pull along with difficulty or effort

The Science of Racing
On Balance

Student Investigation

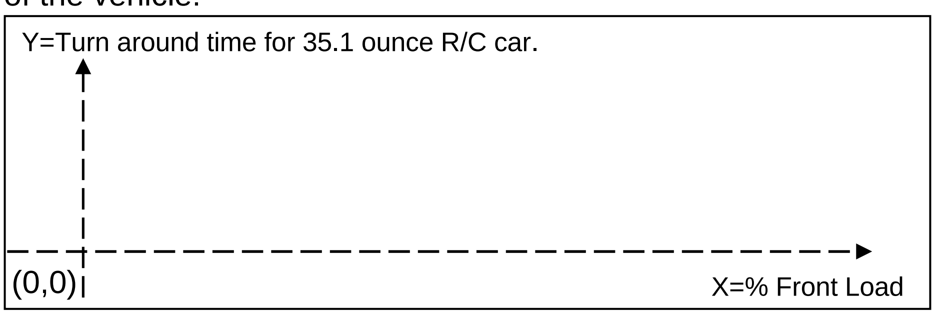
Name _____________Date______

1. State the Objectives: In this activity you will examine the effect that added weight, and **weight balance** have upon the top speed of an RC (radio controlled) vehicle. You will form a hypothesis about what you think will happen as the weight ratio is changed, and make a qualitative graph illustrating their hypothesis.

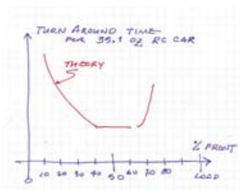
2. What is the Focus Question or Problem: Turning the corners is the limiting process. Going straight is simply about speed but making the turns faster than other cars is the real challenge. How does weight balance affect the turn radius of a car? What turn radius produces the shortest time for the experimental car?

3. Plan an Investigation: Set up a course for the RC car to run; ensuring it is at top speed when crossing the Time Start Line and beginning to measure time. Weight the car so that it runs well in a straight line. Change the front –back weight balance for the car and test it for time on the U-Turn. Each time you change the weight balance, record the ratio of front to total weight and convert this measurement to a percentage. Graph the time for each run with respect to the weight ratio of the car. Determine if balance affects the time and if so what is the most advantageous balance to gain the shortest turn-around time.

4. Make a graph in your Science of Racing Log: Make a qualitative graph showing what you think the turn time will be with regard to weight ratio. Using time to complete a U-turn and return to the start line as the X Axis and the ratio of front to back weight of the vehicle:



These activities are designed to be used with the TI 73 Explorer but are easily adapted to other TI graphing calculators. Educators are invited to Visit ten80Education.com for more lessons on the Science of Racing and to join the Ten80 Education community of engineers, scientists and educators.



5. Set up your investigation.

- Make a plan for collecting data. Assemble materials and practice so that team members know how to read watches, scales, and tape measures and are familiar with the controls on the vehicle.
- Assign roles: Each team requires a driver, timers, a data recorder, calculator of the human kind and a crew chief who keeps track of all materials and schedules for completion of assignments.

6. Set up a weigh station.

- Set up two scales for weighing the car such that the front axel is over the center of one scale and the rear wheels are over the center of the second scale.
- Weight balance will be calculated in terms of the percentage of the total weight which is on the front wheels.
- Procedures for weighing the car,
  - Record the weight on the front end and the back end
  - Turn the car end-for-end and weigh it again.
  - Take the average of the two front end measurements as the front weight, and the average of the two back end measurements as the rear wheel weight.
  - In this case the weight balance is the ratio of the front end weight compared to the total weight, converted to a percentage.

7. Set Up the Car and Track

- Set up a course for the RC car to run; with an in-run section to allow the car to accelerate up to full speed, (S_W), for a car weighing W. You will want to start at least 10 feet from the Start Time line in order to bring the car up to top speed.

- Select a car weight for testing, something in the 27 ounce range for example. From the previous data a car that weighed 26.2 ounces had a top speed of 81.47 inches/sec.

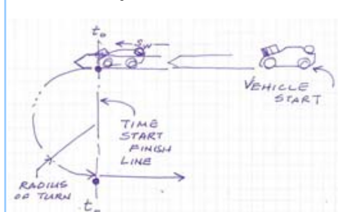
Use Transparency_On Balance_4A to aid in track set-up

Variables

In all of the test runs in this Activity, the total weight of the RC car should be held constant,

The independent variable is the balance of the car. This balance is altered by moving the weights on the car forward or back.

The dependent variable is the time to complete the U-turn is. It is measured from when the car starts its turn at the "start finish" line to when the turn is completed and the car crosses the same line headed back towards its start point.



8. Collect Data

- Have three timers time each test run.
- Start car at start line and begin timing at Time Start Line.
- Record times for each run on the table below

To learn more about the Science of Racing, contact Professor Pi at Ten80education.com

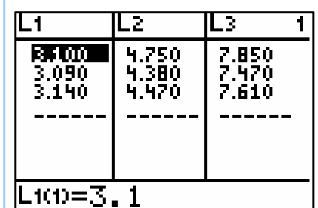
Note: Turn radius

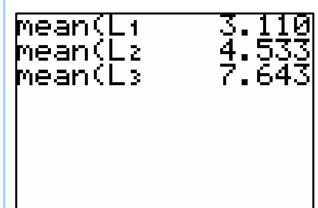
The 1/16th scale cars in the 1080 Education kit have a chassis turn radius of 18”, which means that if this car could turn on that tight a circle it could turn around in 0.74 seconds (which it does not do). If the car is lightly loaded in the front, the turning radius can be large—in the range of 20 feet.

Front Load in ounces	Back Load in ounces	Front weight load as %	U-Turn Time in seconds	Driver	Notes
			Timer #1 Timer #2 Timer #3 Time Total Time Average		
			Timer #1 Timer #2 Timer #3 Time Total Time Average		
			Timer #1 Timer #2 Timer #3 Time Total Time Average		

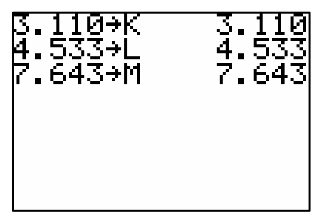
9. Calculate and store Average Times (mean) values

- **Create time lists in the List Editor.** [LIST]
  - Under L1, enter three times for Run # 1: the car running the first part of the course and under L2, enter three times for run # 2: the car running the second part of the course. Continue to add Lists or all runs.
  - Return to the home screen [2nd][QUIT][CLEAR] and calculate the average time for each run.
  - [2nd][STAT][▸][▸]3
  - [2nd][STAT][ENTER][ENTER] for the average of run #1 times
  - [2nd][STAT][▸][▸]3
  - [2nd][STAT][▾][ENTER][ENTER] for the average of run# 2 times
  - Repeat these steps for all runs.





- **Store these average times for later recall.**
  - On the home screen, use the up arrow keys [▴] to scroll up to previous entries and highlight the average for L1. Press enter [ENTER] to place that number at the bottom of the screen. Press [STO▸] [2nd][TEXT][ENTER][▾][▾][▾][▾][ENTER][ENTER]
  - Repeat these steps to store the averages for L2 and L3
  - The values stored for the average times for 3 runs of decreasing weights are A, B, C etc. (You may choose other variables.)



You have your own data. The following directions will use Professor Pi's sample data to demonstrate steps you might take to solve the problem.

See Transparency _ On Balance _ 4A to view data.

Use Professor Pi's Data to practice analysis: Find Optimum Weight Balance.

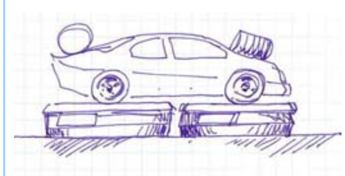
- The professor's radio controlled cars weighed 26.2ounces. He tried four different weight ratios.
- His times for running each weighted car are recorded in the data table below. The table shows the average time calculated from three timers for each rum.
- Sometimes taking a corner slower reduces the travel time significantly. Sometimes, slowing down may equal a faster final time. The weight balance controls the turn radius but another factor is, of course, driver skill.
- Driver skill as a variable is difficult to control. You may want the same driver for every run when you collect your own data.

Sample Data Table A

Front Load in ounces	Back Load in ounces	Front weight load as %	U-Turn average Time in seconds
7.7	18.9		11.86
9.4	17.2		6.74
11.4	15.2		4.34
17	9.6		5.32
19.1	7.5		8.91

To learn more about the Science of Racing, contact

Professor Pi at
ProfPi@ten80education.com

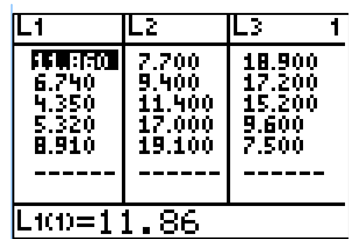


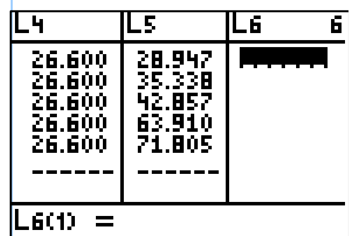
Use Professor Pi's Data

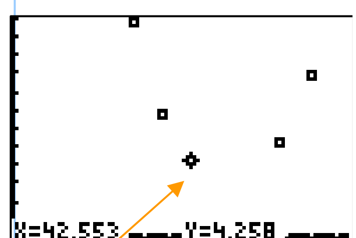
Then collect your own data. Your data may be different because you are running a different vehicle on different surfaces, using different weights and traveling different distances. These are the kinds of problems faced by race teams each time they change tracks, so they collect data that's pertinent to each track on which they race.

10. How was Time affected by changes in weight balance? Graph Time with respect to Weight Balance

- **Clear all lists** [2nd] [MEM] 6 DONE
- **Create four lists from your data table.**
  - Enter stored Average times in L1
  - [2nd][RCL][TEXT][ENTER][▼][▼][▼][▼][ENTER][ENTER] to enter A
  - [2nd][RCL][TEXT][▶][ENTER][▼][▼][▼][▼][ENTER][ENTER] to enter B
  - Continue these steps to enter all times
  - Enter Front Weights in L2. Use arrow keys to scroll up and over. Press [ENTER] after each entry.
  - Enter Back weights in L3
  - Enter formula for total weight in L4
    Highlight L4 [ENTER] [2nd][STAT] [▼]L2 [ENTER]+
    [2nd][STAT][▼][▼][ENTER][ENTER]
  - Enter formula for weight ratio in L5
    Highlight L5 [ENTER] [2nd][STAT] [▼]L2 [ENTER] ÷
    [2nd][STAT][▼][▼][▼][ENTER][ENTER]x100
- **Define a Stats Plot for time as a function of weight ratio graph**
  - [2nd][PLOT] [ENTER] Select ON for Plot 1
  - [▼] [▶] Select the plot [ENTER]
  - Select L5 for XList [2nd][STAT][ENTER][▼] and
  - L1 for YList [2nd][STAT] [▼] [ENTER].
  - Adjust Window value [WINDOW]
  - x min =0   x max=80   Ymin=0 Ymax=12
- [GRAPH][TRACE]







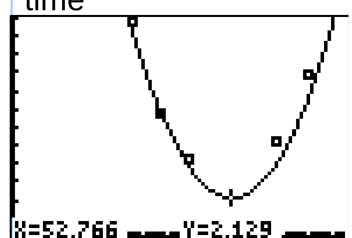
It would appear that the best balance of the car, providing for the quickest path around the curve, one end of a track, occurs at 42.67% of the weight on the front of the car.

11. Your graph is a mathematical model.

It is a model of what you observed just as the radio controlled car models a real car. Scientists and engineers work with mathematical models to make them as accurate as possible.

While it might appear that the best weight ratio for the fastest U-Turn is 42.5%, data analysis is a delicate matter and warrants more careful consideration. Adding a trend line (quadratic regression) used to be a tool only available to very sophisticated problem solvers but now even middle school students can use this handy helper.

time



weight ratio

Adding a trend line to your graph.

[2nd][STAT][▶][▶][▶]6[2nd][STAT][▼][▼][▼][▼][ENTER] to select L5
[,][2nd][STAT][ENTER]to select L1[ENTER]

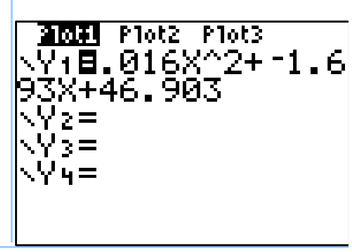
[Y=][2nd][VARS][3][▶][▶][ENTER][GRAPH][TRACE]

The best time (quickest turn) would appear to be at 52.766% on the front wheels giving a time of 2.129 seconds.

Note that as the RC car becomes very heavily weighted in front that the back of the car begins to over rotate, it "over-steers," or in racing jargon it's "loose." Think about which tires are driving the car and which tires are steering it.

Math offers scientists and engineers a way to look at things that are otherwise invisible. In this case the numbers show you the best car set up.

The equation that describes this trend line is $y = a\,x^2 + b.x + c$



Write the equation under [Y=] that describes your graphic model.

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- Analyze your own data following the same steps used with Professor Pi's data set.

Compare your findings and discuss why your numbers may or may not be in the same range.

Notes from a race engineer to help you make sense of your numbers.

The U-turn times are very sensitive to the RC car used, the floor surface (carpet, hard linoleum, concrete, etc.), the condition of the floor (a dusty hard linoleum surface offers very little traction), and weather conditions (temperature and relative humidity changes the friction of linoleum floors dramatically).

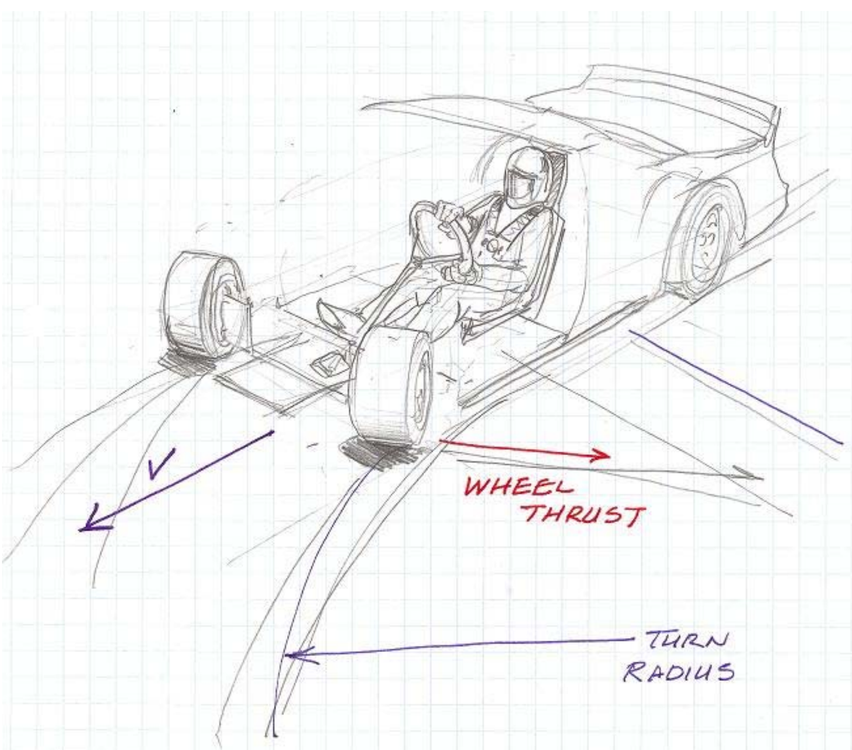
This is precisely the process that race car engineers go through. The next run the race team would make would be for a car with 52.128% of the weight on the front of the car.

That data would be plotted, a new trend line made, and another better balance calculated, over and over and over, for dozens of runs. The race that one watches on TV is a very small fraction of the time a race team spends driving at race speeds in testing. The actual race is their short day. In a longer extension of this activity you could continue to pursue the optimal balance for the car with additional tests.

The picture to the left illustrates a race car engineer, the Pi car's driver, weighing the car to calculate the weight balance from which he will make adjustments based on test run data. Note the ever present essential TI calculator in hand.

The data will show that weight balance greatly affects the speed of turning. It will also offer an opportunity to show that more data fills in a picture that is difficult to see with fewer points. A trend line in the form of a quadratic regression demonstrates that the maximum point may not show up in a few data points, but the calculator and statistical tools can help students find that point. While middle school students may not understand the math behind the trend line, the idea of a best fit curve is well within their grasp. The main idea should be that data tells a story and the more you think about it and find patterns in it, the more complete is the story that evolves.

a) **Read the Historical Background paper** written by the engineers and educators of 1080 Education. There is a lesson in the background paper about how the same forces that keep planets in orbit also keep race cars on the track.



Assessment:

1. How does the actual data compare to the prediction you made?

2. If a body is being pulled in a circle and the force stops, what direction does the body follow?

3. What were the variables in this investigation?

4. How do mass, velocity and acceleration relate to each other in this investigation?

5. What causes a “tight” car? What causes a “loose” car?

Assessment:

1. How does the actual data compare to the prediction you made?
   - *Answers will vary*

2. If a body is being pulled in a circle and the force stops, what direction does the body follow?
   - *In a straight line tangent to the circle at the point at which the force stopped.*

3. What were the variables in this investigation?
   - *Independent: weight balance*
   - *dependent: time*

4. How do mass, velocity and acceleration relate to each other in this investigation?
   - *$F = ma$*

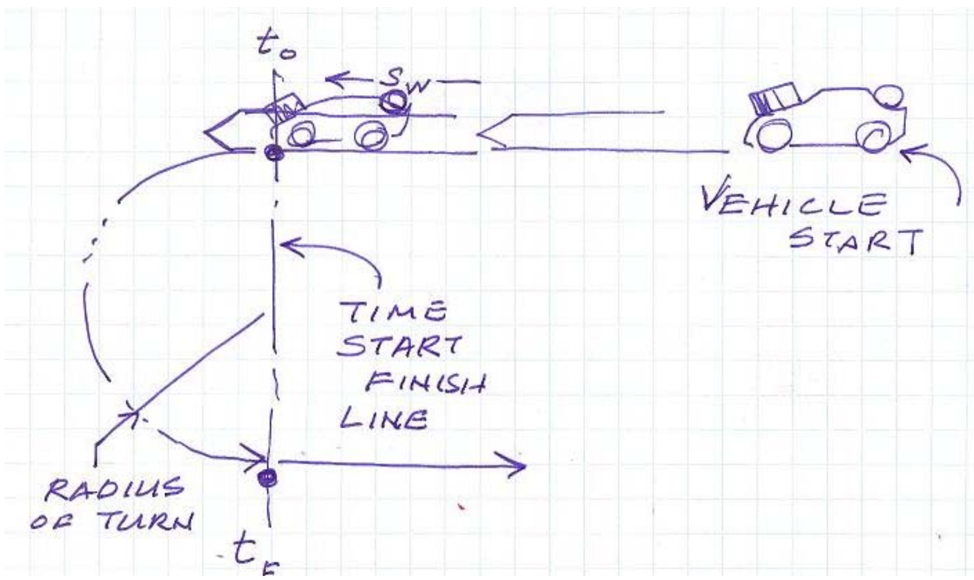
5. What causes a "tight" car? What causes a "loose" car?
   - *Car pushes, will not turn, needs more weight on front*
   - *Cat spins out, back tries to pass the front, needs more weight on back.*

Use Professor Pi's data to practice analysis:

Find Optimum Weight Balance

26.2 ounces.

Total weight



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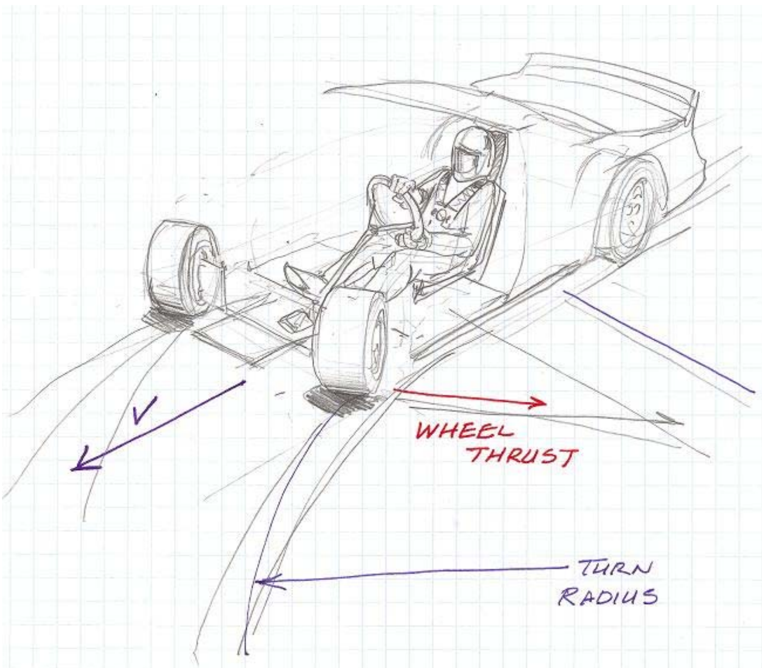
The Science of Racing
On Balance

Transparency _ On Balance _4B
Solutions

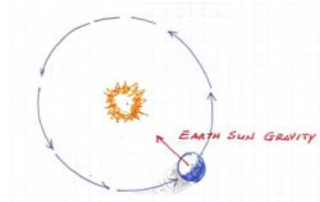
Use Professor Pi's data to practice analysis:

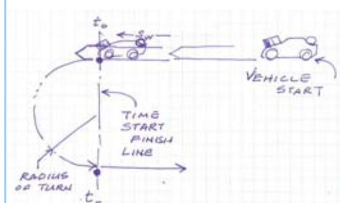
Find Optimum Weight Balance



Sample Data Table A

Front Load in ounces	Back Load in ounces	Front weight load as %	U-Turn average Time in seconds
7.7	18.9	28.9	11.86
9.4	17.2	34.3	6.74
11.4	15.2	42.8	4.34
17	9.6	63.9	5.32
19.1	7.5	71.8	8.91





26.2 ounces.

Total weight