The Science of Racing Series

Activities Created by Ten80 Education
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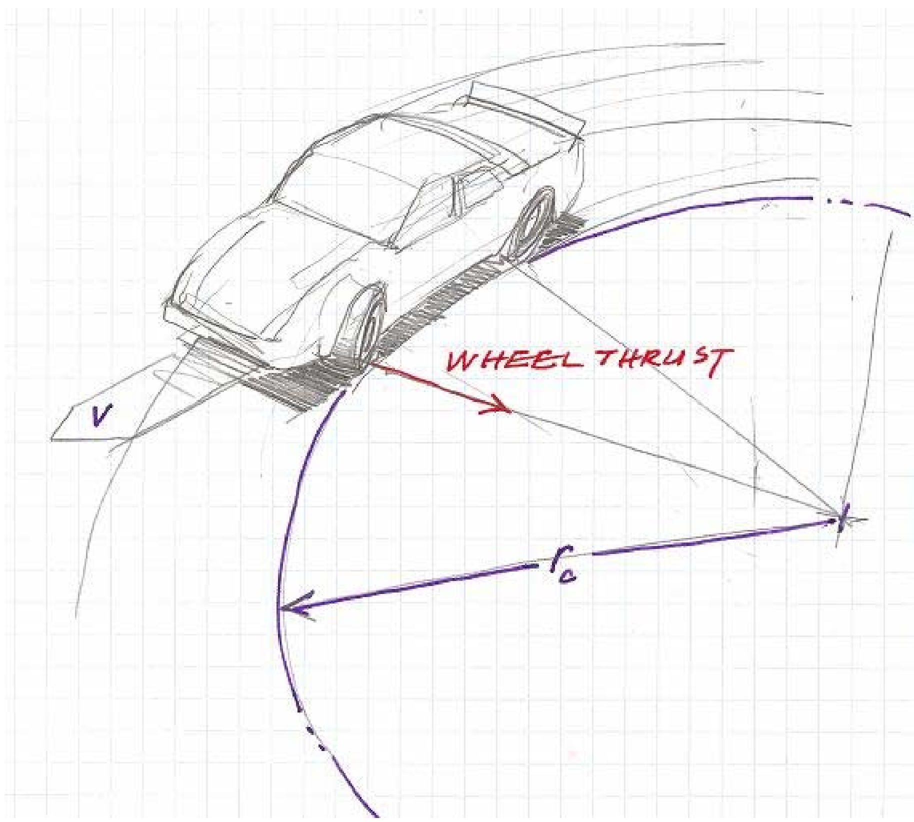


Activity 3: Newton Knew

The Science of Racing
Newton Knew

Activity Overview

F = m a

For race car engineers, ***F*** = m ***a***, is the backbone of their calculations. F is force, m is mass and a is acceleration. For example, selecting gear ratios relies on this relationship.

Race cars engine are limited in terms of both power and speed (expressed as revolutions per minute, or RPM). The RPM limits are set by the racing organization for some series like the F1 (16,000 RPM) Champ Cars, and Legends (10,200 RPM in Legends). In other series, the RPM limits are set by the individual teams.

Faster engines (i.e. higher RPM engines) produce more power, but they also stress the parts more which makes them more likely to disintegrate during a race. How fast is fast enough to stay ahead of other racers but not so fast that the engine blows up during a 400 mile race? The answer is very carefully calculated and a closely guarded secret within a race team.

In selecting gears, the race engineer faces a compromise. For any given engine, the choice is between one of the following two options.

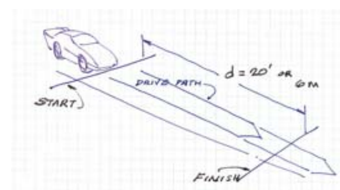
High acceleration rates but low top speed, OR

Lower acceleration rates but higher top speed

The choices are mutually exclusive as illustrated below.

Recall that the slope of a line for speed-time is acceleration.

Activity at a Glance:
Grade: 6-9
Subject: Phys Science
Topic: F=ma
Time: 2x45-min periods



Visit the engineers and educators of Ten80 Education at

www.ten80education.com

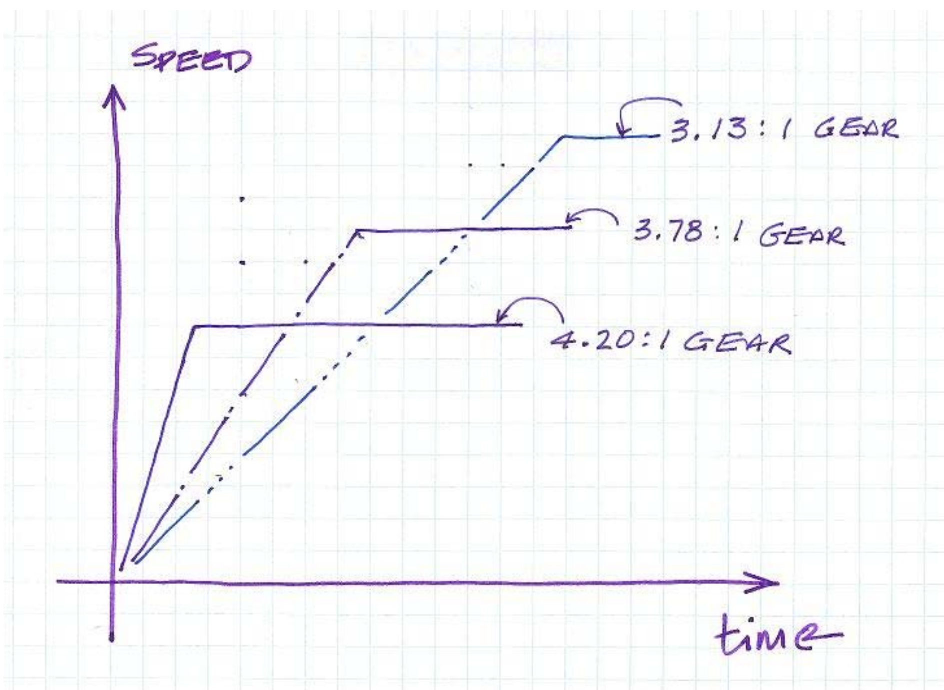
Materials:
- TI-73 Explorer
- Student Handout
- Transparencies with sample data: Newton Knew_3A and 3B
- Background Paper: F=ma Article: Science of Racing

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.)

F = m a

The increments between ratios available are very small (4.20, 4.19, 4.17, 4.15, etc.). The optimal choice for any particular race track requires a very complex set of calculations combining Newton's Second Law for the race car on a given track and weather conditions, plus statistical analysis of engine tests (for power, torque, and durability).

> The gear ratio is defined as the (engine RPM) / (drive wheel RPM), which is determined by the gear-set that is placed in the differential of the race car. The engine RPM is 10,200 in this example. Only three gear ratios are shown in this sketch, whereas a top of the line professional race team may have 60 or 70 different gear-sets for each race car.



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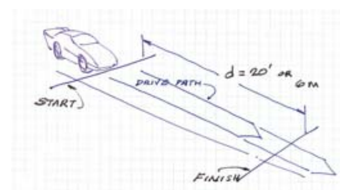

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The Science of Racing
Newton Knew

Student Investigation

Name ______________Date______

1. State the Objectives:

Create a graph of data you collect (a mathematical model) which can be used to make predictions about the speed and acceleration of radio-controlled (RC) cars of different weights. Distinguish between speed, velocity and acceleration.
Substitute variables for numbers.

2. State the Problem:

For race car engineers, ***F*** = m ***a***, is the backbone of the vast majority of calculations. The selection of gear ratios is one example. How does this formula define the relationship between the weight (mass) of a vehicle and its acceleration, i.e., how long it takes to accelerate from standing start to a constant (maximum) speed? What is the relationship between force, speed, mass, distance and acceleration?

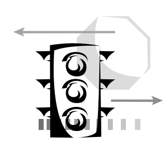
3. Plan an Investigation:

Set up a track on which a weighted vehicle will travel from zero speed to top speed. Time the event. From the collected data, determine top speed, the time it took to reach top speed and its rate of acceleration. Use the data to create a mathematical model in the form of a graph to show the relationship between speed, time, distance and acceleration.

4. Make a graph in your Science of Racing Log.

Make a graph showing what you think the motion of the car is when it begins to move at a red light and travels forward on a 45 mile per hour road.

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 1080 Education community of engineers, scientists and educators.

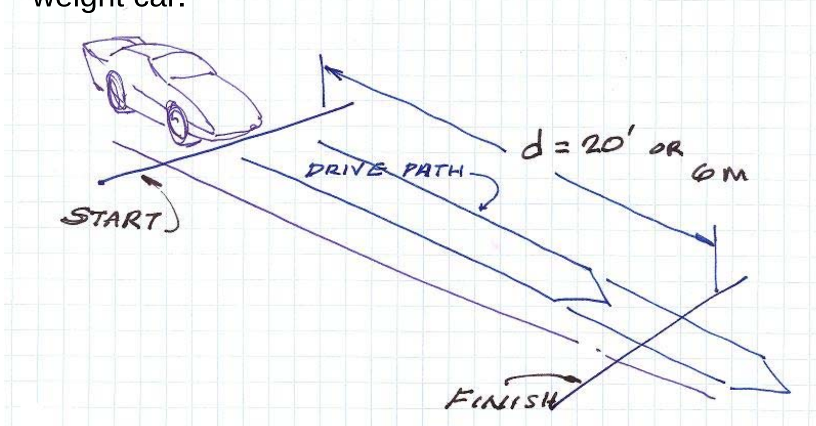


5. Set up your investigation.

- 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 the Car and Track

- From START, mark the Finish Line# at approximately 240 inches and mark with tape. This is the line at which timers stop their watches. The car should be up to top speed and continue moving at that speed past the Finish Line. (These are suggested measurements and can be adjusted to meet size constraints of your classroom or hallways).
- Add weights to a radio controlled car. The weights can be washers taped to the car or soda bottles with water added. Each team should make a run with a different weight car.



See transparency _ Newton Knew_3A for track plan

Vocabulary:

Speed
Distance traveled in some amount of time or
speed = d / t

Velocity
Speed in some direction.

Average speed describes speed of motion when speed is changing.

Instantaneous speed is speed at a given point of time.

Constant Speed describes motion in which speed is not changing.

Constant Velocity describes motion in which neither speed or direction are changing.

7. 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

ProfPi@ten80education.com

Data Table A

Time of acceleration (t_a) In seconds	Rate of acceleration (a) In/sec^2	Average Time (t_f) in seconds	Average Speeds (S_w) In inches/second	Weight (W) in ounces	Distance (d) In inches
		Timer #1 Timer #2 Timer #3 Time Total Time Average			240 in
		Timer #1 Timer #2 Timer #3 Time Total Time Average			240 in
		Timer #1 Timer #2 Timer #3 Time Total Time Average			240 in

8. Calculate and store Average Times (mean) values

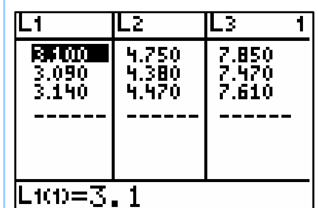
- **Create time lists in the List Editor.** [LIST]
  - Under L1, enter three times for Run # 1: the car running the first part of the course and under L2, enter three times for run # 2: the car running the second part of the course.
  - Return to the home screen [2nd][QUIT][CLEAR] and calculate the average 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

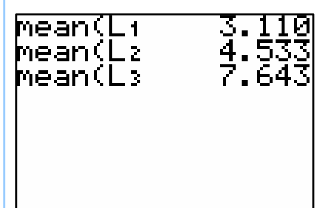
- **Store these average times for later recall.**
  - On the home screen, use the up arrow keys [▲] to scroll up to previous entries and highlight the average for L1. Press enter [ENTER] to place that number at the bottom of the screen. Press [STO►] [2nd][TEXT][ENTER][▼][▼][▼][▼][ENTER][ENTER]
  - Repeat 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 and C. (You may choose other variables.)

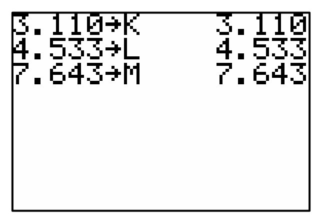
9. You have your own data. The following directions will use Professor Pi's sample data to demonstrate steps you might take to solve the problem.

Read "Acceleration: Background Understanding"
See Transparency _ Newton Knew _ 3A to view data.

Sample Data Set







Use Transparency Hitting the Mark_2A for Sample Data Set

READ the background article, "Acceleration", Learn how it "looks" on a graph.

10. Define a Relationship between speed of the car and its weight. What top speed can you expect from a car as its weight varies?

Professor Pi planned to make three test runs with 1/16 scale radio controlled cars that weighed 30, 45 and 60 ounces. Before each run, the car's exact weight was recorded. The distance of each run was 240 inches.

- Professor Pi collected data using scale model R/C cars; the data used for illustration is taken from 1/16th scale R/C cars used in the 1080 Education kits.
- In order to define a relationship between the weight of the car he used and its speed, he and his students ran speed tests that generated the following data: (you may obtain your own data by doing the Time Laps Activity).

Weight	Speed
88.7 oz	48.37 inches/sec
23.6	82.82

- From this data using their TI73 Explorer they generated a linear equation for the line passing through the data points in the form of:
  Y = a X + b; where Y = speed, and X is the car's weight
- With the data above we obtain following equation for the line that passes through the Speed-Weight data points:

$$Y = a X + b$$

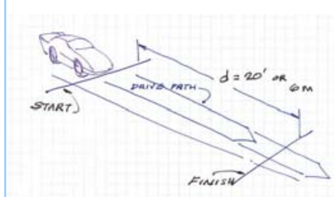
$$\text{Speed} = (-.529)(\text{Weight}) + 95.31 \quad \text{or}$$

$$\mathbf{S_W = -0.529 \cdot W + 95.31}$$

- You may use this equation or generate your own by doing the Time Laps Activity. Enter this equation into the TI 73 Explorer calculator .[Y=][−][5][2][9][x][+][9][5][.][3][1][ENTER]

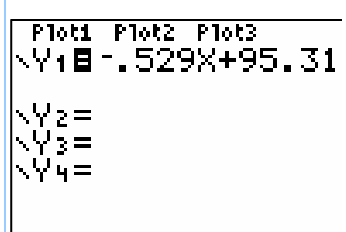
Use Professor Pi's Data

Then analyze your own data. Your data may be significantly 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 pertinent to each track on which they race.



Your screen should look like this:

If you substitute a car weight for x and solve the equation, you will get the speed you can expect from that car. Y = speed.



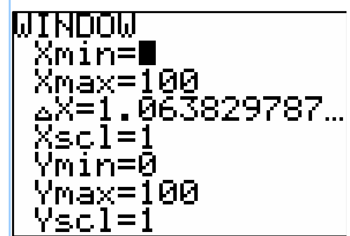
The Science of Racing
Newton Knew

Data Analysis: Use Professor Pi's Data

What do you know and what do you need to know?

From the data collected you know the weights of each vehicle and the total time it took to run 240 inches. From previous data collection, you have an equation --a math model-- for the relationship between weight and speed for these vehicles. From the table and/or graph you can find the top speed of each weighted vehicle.

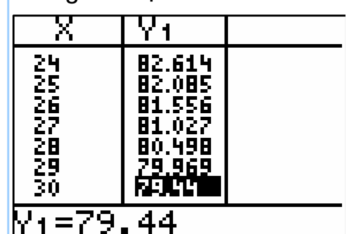
Sample Data Set

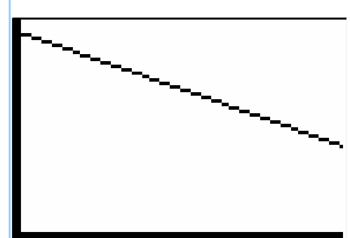


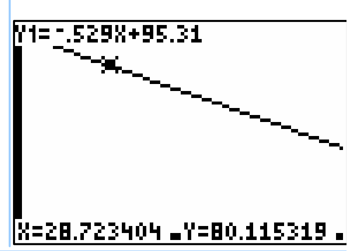
11. Graph Speed with respect to eight to find the predicted Top Speed of vehicles you have not yet tested.

- **Clear all lists** [2nd] [MEM] 6 DONE[ENTER]
- Stats Plot should be OFF. [2nd][PLOT] Select OFF [ENTER]
- Adjust Window value [WINDOW]
  x min =-0 x max=100 Ymin=-0 Ymax=100
- [GRAPH] to view the graph of the equation you entered. Speed is on the Y axis and Weight is on the X axis.
  - You may use the trace button on the graph, [GRAPH][TRACE] to scroll along the X axis until you locate ~30 and note the corresponding Y value of ~80.
- The calculator has created a table [TABLE] of weights in x and the top speeds for that weight of car in the Y column.
  - You can check there to find the 30 ounce car and its top speed of 79.44.
- Following these steps, complete the data table with speeds for each weight car.

Weight Speed





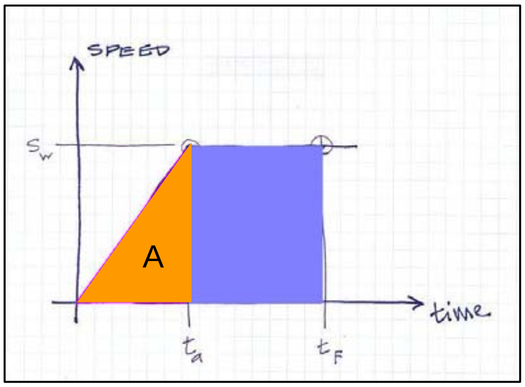


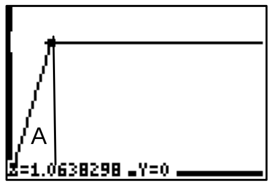
Weight (W)	Average Time (t_f)	Average top Speeds (S_w)	t_a	d
28.9 ounces	3.84 seconds	79.44 in/sec		240 in
45.5 ounces				240 in
66.6 ounces				240 in

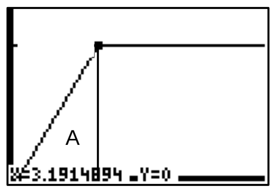
What do you know and what do you need to know?

You know the weights, final times, top speeds and distance. You still do not know how much of the total time was used to accelerate the vehicle up to its top speed. That is the distance represented by the triangle on the Speed-Time graph. This time of acceleration can now be calculated.

Read Background Article, "Acceleration".







You do not yet know the shape of the triangular part of this curve.

How fast did the car arrive at its top speed?

VARIABLES

S_W	**Top Speed of a vehicle that weighs W ounces**
t_a	**time to accelerate to constant speed for S_W vehicle.**
t_F	**time to Finish for S_W vehicle**
d	distance

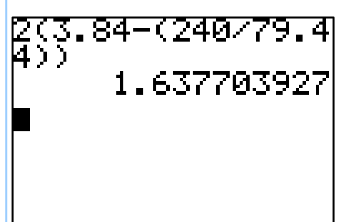
12. Calculate the time of acceleration.

- The total area of the two parts of the graph in Professor Pi's drawing equals the distance, d. The area of the triangular part is ½ bh or: $\frac{1}{2}(t_a)(S_W)$
- And the total area of both the triangle and the rectangle is:

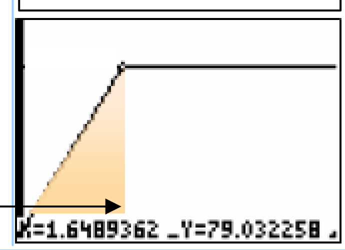
$$\frac{1}{2}(t_a)(S_W) + (S_W) * (t_F - t_a) = d$$

- Using a bit of algebra to rearrange terms we can solve for ta, the only part of this equation we don't know:
  (d) = 240 inches;
  S_W = 79.5 inches/second;
  t_F = 3.84seconds

$$t_a = 2 * \left(t_F - \frac{d}{S_W}\right)$$



Therefore for 1.64 of the total 3.84 seconds of the run for this car, the car was accelerating from 0 to 79.5 inches per sec. The rest of the run, 2.2 seconds, was made at top speed. **t_a, the time for acceleration, is 1.64 seconds**



What do you know and what do you need to know?

Sample Data Set

You know the distance, weights, final times, time required to accelerate this mass (weight) up to top speed and top speeds. You still do not know the rate of acceleration. How many inches per second was the speed increasing each second? This can now be calculated.

13. Calculate the Rate of Acceleration

- The acceleration rate is the speed obtained, S_W or 79.5 inches/sec, divided by the time to accelerate, 1.642 seconds; or a = 79.4inches / second / 1.642 seconds
- Return to the Home screen
  [2nd][MODE][CLEAR] [7][9][.][4]÷[1][.][6][4][2][ENTER]

```
79.4/1.642
      48.35566382
```

- The rate of acceleration is ~ 48 inches/second/second also written as 48 in/sec^2

Now you can complete the Professor's Data Chart for his 28.9 ounce car and prepare to collect your own data on your own vehicle. The Professor was curious about whether F=ma really explained his data, so he completed two more runs with heavier cars and used all three data points to find out if mass times acceleration really is a constant number.

Weight (W)	Average Time (t_f)	Average Speeds (S_w)	d	t_a	Rate of acceleration
28.9 ounces	3.84 seconds	79.44 in/sec	240 in	1.64 sec.	48.36 in/sec^2

Is m*a always the same for a given force? The force in this case is the energy output of the motor driving the radio controlled car. Take a look at what he found.

The Science of Racing

Newton Knew

Data Analysis: Use Professor Pi's Data

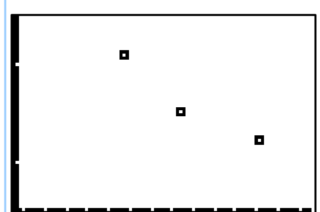
14. Is mass × acceleration a constant number for a given force? Graph Acceleration and test Newton's theory of F=ma (force = mass × acceleration)

- When Professor Pi completed two more runs his data looked like this. In this table X = Weight, (note that Weight = m*g, in ounces); and Y = acceleration in in/sec2.
- Essential question: what story (theory, hypothesis, mathematical model) would explain the observed data?
- Use graphs to look for patterns in the data. The one that caught the attention of Kepler and Newton is evident when you multiply weight by acceleration.

X	Y
Weight (W) is on the X axis	**Rate of acceleration is on the Y Axis**
28.9 ounces	**48.36 in/sec²**
45.5 ounces	**30.94 in/sec**
66.4 ounces	**22.13 in/sec**

- **Use Lists to multiply *weight (m*g) by acceleration to see if this product is a constant as Newton predicted.**
- **Clear (or Store) all lists** [2nd][MEM][6][ENTER]
- **Create three lists from your data table**
  - o [LIST]
  - o Enter 3 weights (m*g) in L1
  - o Enter 3 Acceleration rates (F/m) in L2
  - o Enter formula for weight times acceleration in L3
    - o Highlight L3 [ENTER][2nd][STAT][×] [2nd][STAT][▼][ENTER] [ENTER]
  - o Your lists have weight in L1, acceleration rate in L2 , and weight x acceleration in L3
  - o Notice that the products in L3 are nearly the same number. (or at least reasonably close given the unsophisticated nature of this experiment - the range of the data is only 4% of the average, 1441.6).

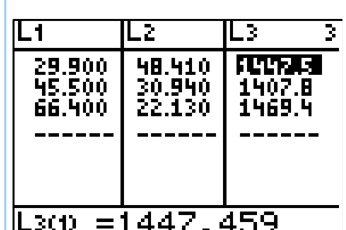
Acceleration



Weight

Y = 87.283 * .979 X

is the equation that describes the curve through the points



The genius of Newton is that from precisely such a data set he put together the theory of: *F* = m*a*, or for a constant force (in this case the motor driving the RC car) the acceleration, a, is: a = F/m.

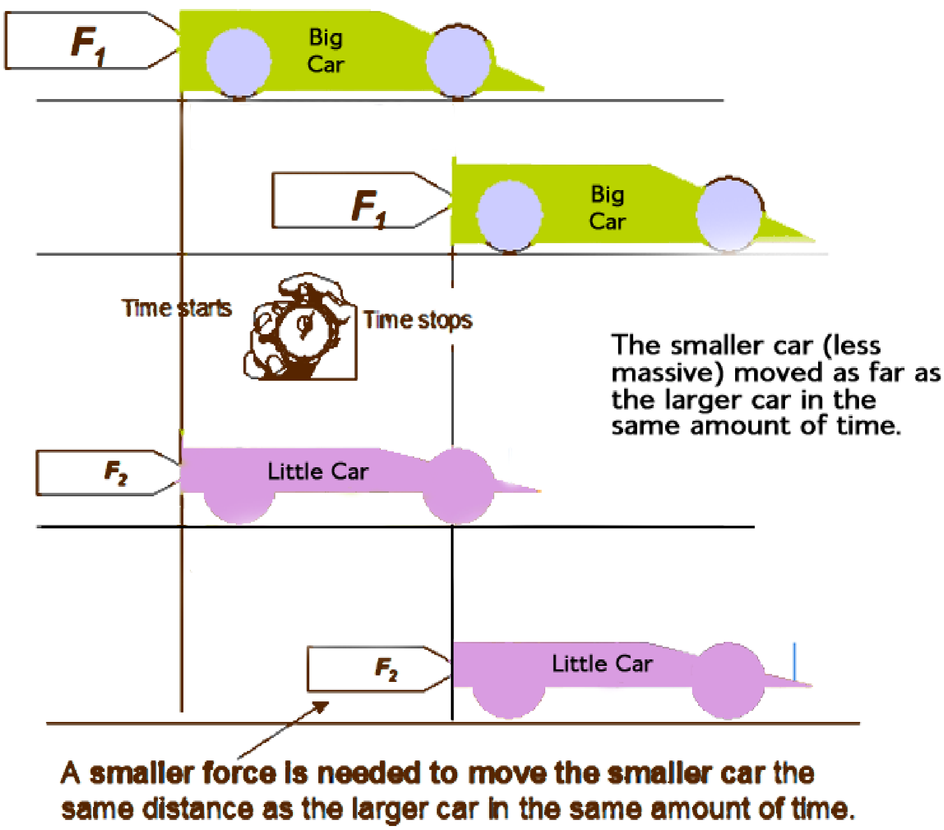
*Note that in this activity, we are examining F=ma using weight and mass interchangeably because on earth the two are directly proportional.

15. Graphs are mathematical models.

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.

Force= mass x acceleration

In your Science of Racing Log, create a series of hand drawn graphs and/or diagrams representing your understanding of F=ma.



Assessment

- What is acceleration?

- How can you use a Speed-Time graph to determine distance traveled?

- What is the relationship between Speed, time and distance?

- What is your understanding of F=ma?

- How is acceleration calculated? What are the units of speed and time?

Assessment

- What is acceleration?

  See Vocabulary

- How can you use a Speed-Time graph to determine distance traveled?

  Divide the area under the graph lines into sections for which you can find the area.

- What is the relationship between Speed, time and distance?

  Speed equals distance divided by time.

- What is your understanding of F=ma?

  mass times acceleration is a constant for a given force. If mass decreases, acceleration increases. If acceleration increases, mass decreases.

- How is acceleration calculated? What are the units of speed and time?

  a = change in speed divided by change in time.

Vocabulary:

Speed
Distance traveled in some amount of time or
speed = d / t

Velocity
Speed in some direction.

Average speed
describes speed of motion when speed is changing.

Instantaneous speed is speed at a given point of time.

Constant Speed
describes motion in which speed is not changing.

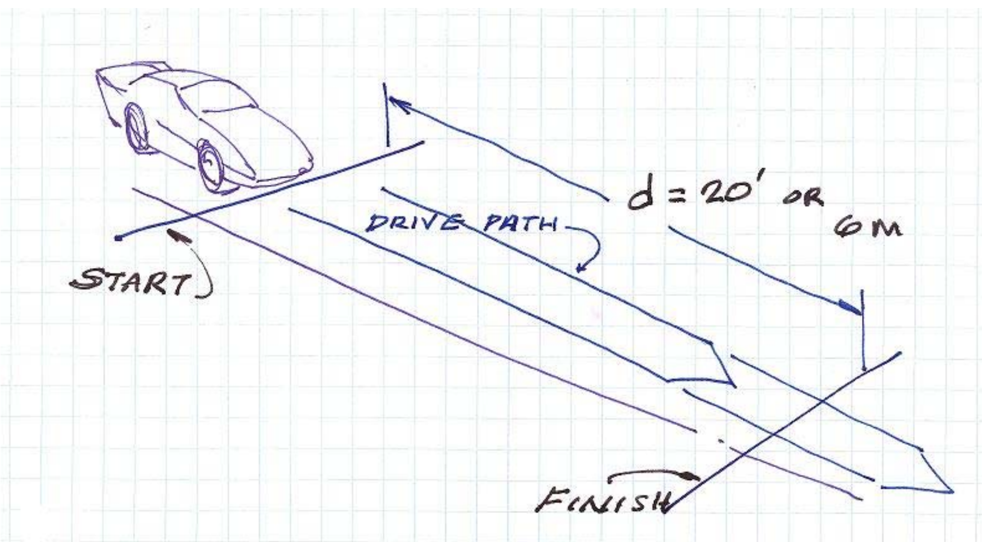
Constant Velocity
describes motion in which neither speed or direction are changing.

Acceleration
is a change in speed or direction.

Use Professor Pi's Data: Find Acceleration

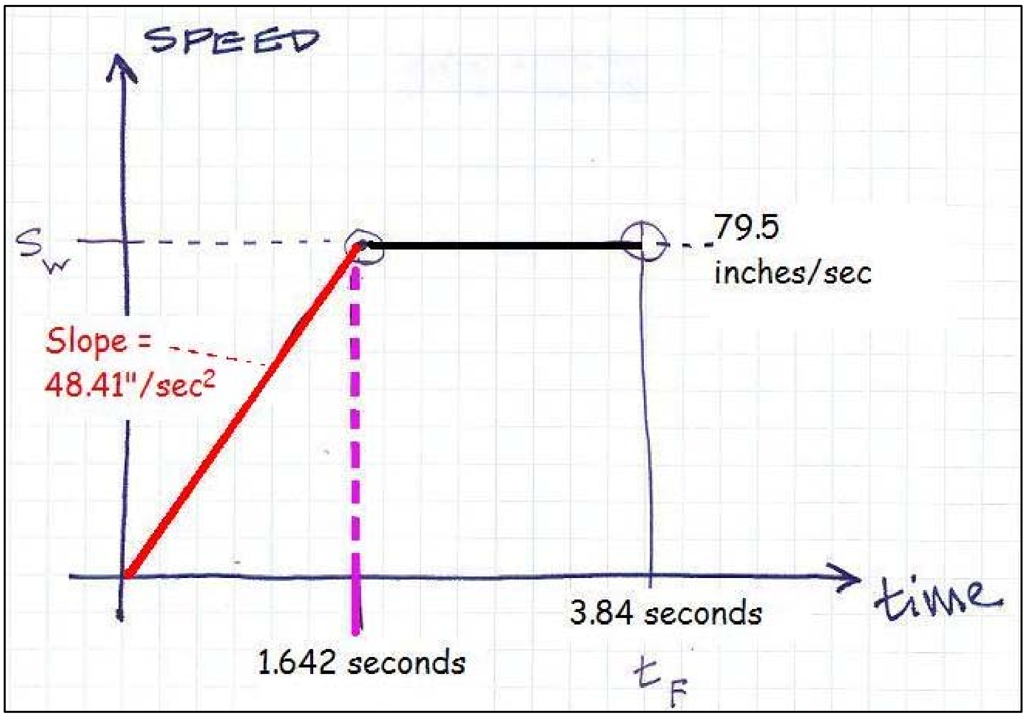
Notes:

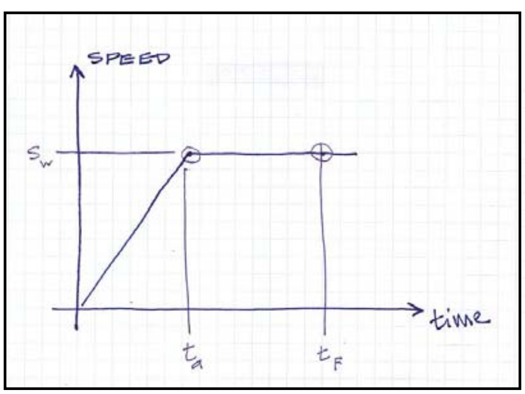
- Professor Pi planned to make three test runs with 1/16 scale radio controlled cars that weighed 30, 45 and 60 ounces. Before each run, the car's exact weight was recorded. The distance of each run was 240 inches.
- Professor Pi collected data from use scale model RC cars; the data used for illustration is taken from 1/16th scale RC cars used in the 1080 Education kits.

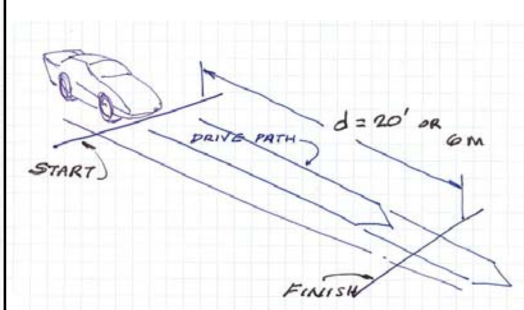


Weight (W)	Average Time (t_f)	Average Speed (S_w)	d	t_a	Rate of acceleration
28.9 ounces	3.84 seconds	____________ in/sec	240 in	_____ sec.	________ in/sec^2

Weight (W)	Average Time (t_f)	Average Speeds (S_w)	d	t_a	Rate of acceleration
28.9 ounces	3.84 seconds	79.44 in/sec	240 in	1.64 sec.	48.36 in/sec^2
45.5	3.37	71.2	240 in	30.94	30.94
66.4	3.99	60.19	240 in	30.94	22.13







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Newton Knew

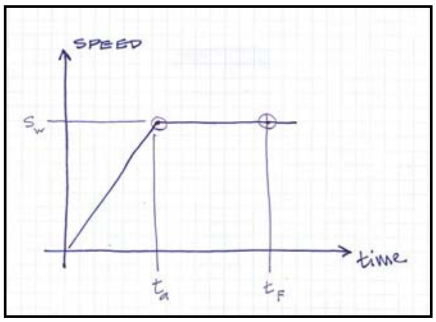
Newton Knew Acceleration: Background

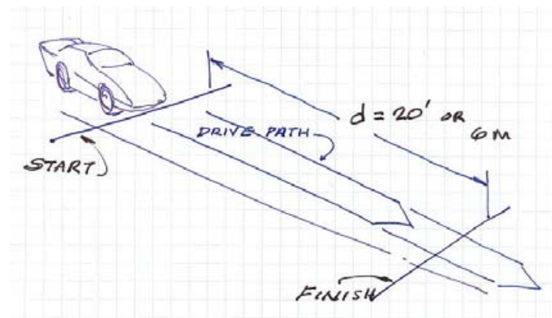
This is a classic problem in physical science: a force applied to a real object (one that has mass) will cause the object to accelerate. In the case of a free falling object in air, the object continues to accelerate until it reaches a speed where the drag due to air friction equals the downward pull of gravity.

At this point the forces are balanced, i.e., sum is zero, and acceleration goes to zero, but the object continues at a constant speed: its terminal velocity (the most critical parameter describing the effectiveness of a parachute).

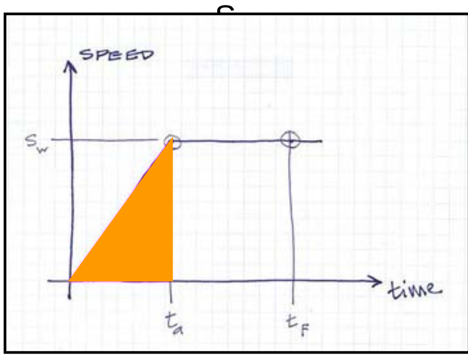
While this idea of a free falling object is difficult to examine in the classroom this activity illustrates the same principles.

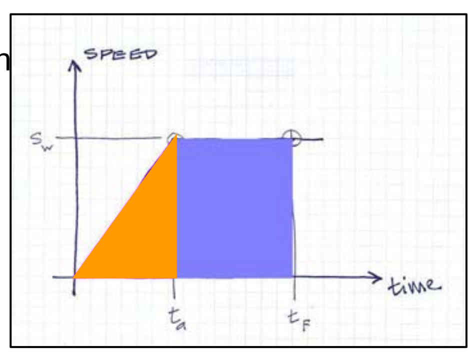
Think abut how fast a change is taking place: the rate of change.
How does a picture (graph) help examine the relationship between the speed of a vehicle and how quickly it is able to obtain its top (constant) speed. A change in speed or direction is called acceleration.



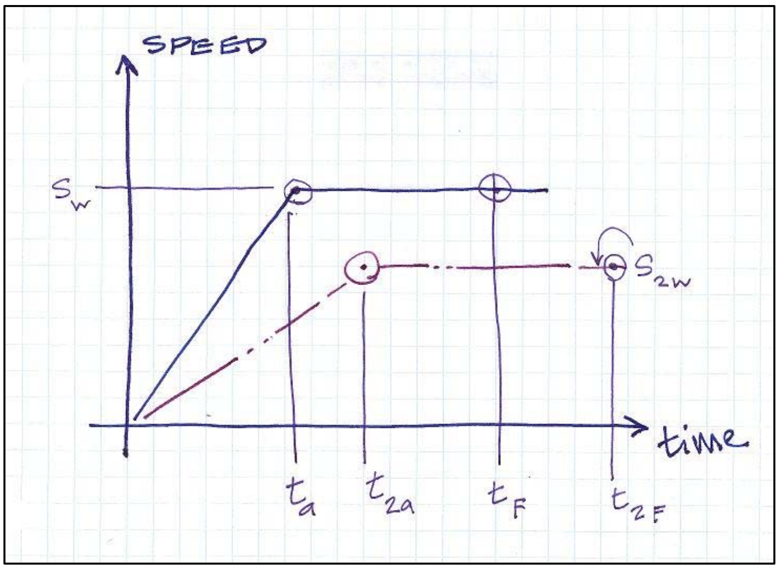


– The line that describes speed with respect to time has two parts, an uphill slope from zero sum time to a point labeled “t sub a”, at which point the car has obtained its top speed, and then a another horizontal section illustrating constant speed, “S sub W”, the top speed of a car that weighs W.
– In this activity the ending time, “t sub F”, is when the car crosses the finish line, a distance, d, from the start line.
– The *area* under the speed line has two parts: a triangular section when the car is accelerating and a rectangular section after the car has obtained its top speed, where the car is running at a constant speed, S





- One would expect that as the vehicle gets heavier, having a greater mass, it will accelerate more slowly.



- In this sketch, the maximum speed (S_{2W}) of the heavier vehicle is less (it is slower) than for the lighter vehicle (S_W).

- This concept is the essence of Newton's Second Law. For a given force, F =ma:
  - The acceleration of the vehicle will be inversely proportional to its mass.
  - This is how Newton originally phrased this concept: for a given force applied to an object, its mass and acceleration will be inversely related;
  - or mass multiplied by acceleration equals the force, F, defined as a constant.
  - In this experiment, i.e., F = m a. F will represent the maximum push the electric motor in the RC car can deliver.

VARIABLES

S_W	**Top Speed of a lighter vehicle that weighs W ounces**
t_a	**time to accelerate to constant speed for lighter S_w vehicle.**
t_F	**time to Finish for lighter S_w vehicle**
S_{2W}	**Top Speed of a heavier vehicle**
t_{2a}	**time to accelerate to constant speed for heavier S_{2w} vehicle**
t_{2F}	**time to Finish for heavier S_{2w} vehicle**
d	**distance**

Science of Racing Series

Correlations to National Science Standards

Activities 01 - 06

☑ Comprehensive coverage ✓ Partial coverage

PROGRAM STANDARD C:
Mathematics is important in all aspects of scientific inquiry.

The science program should be coordinated with the mathematics program to enhance student use and understanding of mathematics in the study of science and to improve student understanding of mathematics.

ACTIVITIES

1	2	3	4	5	6
☑	☑	☑	☑	☑	☑

PROGRAM STANDARD B:
Properties & changes of properties in matter , Motions and forces, Transfer of energy

MOTIONS AND FORCES

The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph.

An object that is not being subjected to a force will continue to move at a constant speed and in a straight line.

If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion.

ACTIVITIES

1	2	3	4	5	6
☑	☑	☑	☑	☑	
✓	☑	✓	✓	✓	
			☑		

TRANSFER OF ENERGY

Energy is a property of many substances and is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. Energy is transferred in many ways.

Heat moves in predictable ways, flowing from warmer objects to cooler ones, until both reach the same temperature.

Electrical circuits provide a means of transferring electrical energy when heat, light, sound, and chemical changes are produced.

In most chemical and nuclear reactions, energy is transferred into or out of a system. Heat, light, mechanical motion, or electricity might all be involved in such transfers

ACTIVITIES

1	2	3	4	5	6
✓	✓	✓	✓	☑	☑
					☑
				☑	☑
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CONTENT STANDARD D:

Most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses.

1	2	3	4	5	6
			☑		

CONTENT STANDARD G:

The introduction of historical examples will help students see the scientific enterprise as more philosophical, social, and human. Middle-school students can thereby develop a better understanding of scientific inquiry and the interactions between science and society.

1	2	3	4	5	6
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