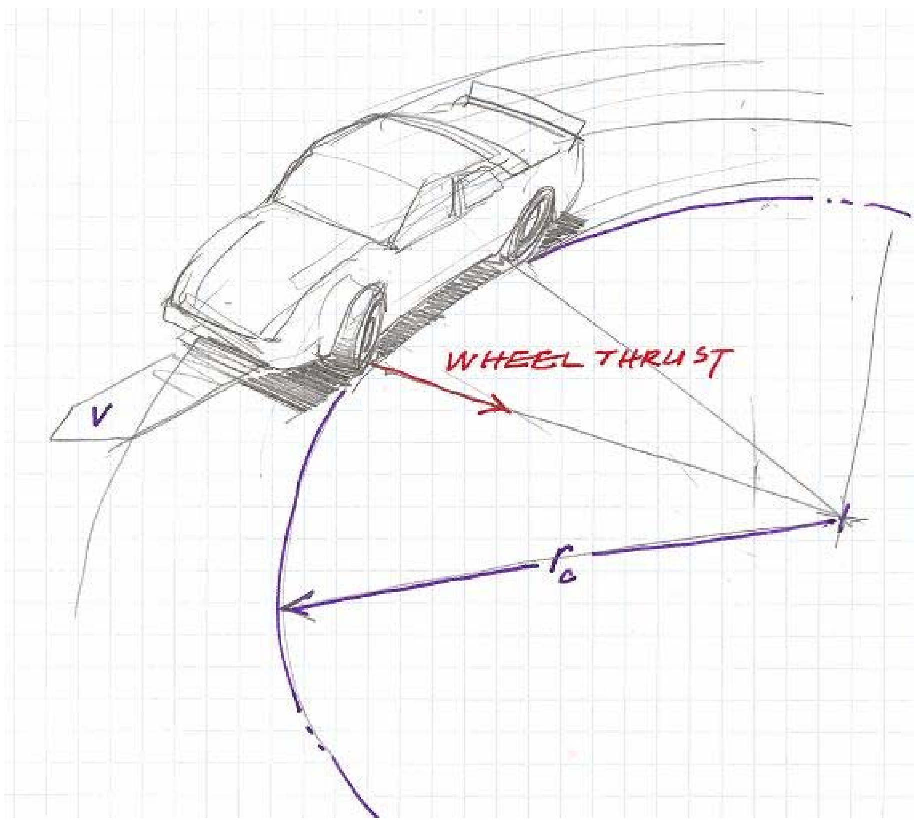
The Science of Racing Series

Activities Created by Ten80 Education
and Texas Instruments

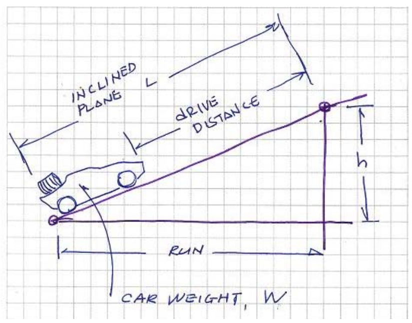


Activity 5: No Free Lunch

There's No Free Lunch

Maximizing work output from energy input is a classic physical science challenge. In this activity you will examine the relationship between work done by driving an R/C (radio controlled) vehicle up an incline and the input energy from the alkaline batteries. You will also examine speed, time and distance traveled by the RC vehicle (or any vehicle).

A force applied to a real object (one that has mass) will cause it to move and does work in the process. Work is defined as the applied force multiplied by distance moved. This output of work done comes at a price, the energy input required to drive the process.



A fact of reality (also called the Second Law of Thermodynamics) is that the input energy is always greater than the output work. Sometimes the ratio is very close to 1 (0.99), but is never actually 1.0. The output work done by production cars on the street moves the car down the highway. This work is seldom more than one-fourth of the work potential contained in the gasoline tank of the car. The majority of the energy in the gasoline is lost to the surroundings as waste heat.

Electric cars have been available since the first days of the automobile. The gasoline-powered cars dominated the car market because the energy density of gasoline is higher than that of batteries which store electrical energy.

Though most popular racing series still run gasoline-powered (or methanol-powered) cars there are a small but growing number of races for electric-powered cars. In fact, the fastest accelerating street legal car is the electric-powered T-Zero from AC Power in California.

Activity at a Glance:

Grade: 6-9
Subject: Physical Science
Topic: Conservation of Energy, Voltage, Work, Power
Time: 2x50-min periods

Visit the engineers and educators of Ten80 Education at

www.ten80education.com

Materials:

- TI-73 Explorer
- DATAMATE
- CBL
- Student Handout
- Transparencies with sample data: No Free Lunch 5A and 5B
- 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 Science of Racing

No Free Lunch

Activity Overview

Race teams are extremely concerned about the fuel (real energy) consumption of their car.

All race series limit the size of the fuel tank in the car, and the car needs to make some number of pit stops to refuel during a race. If the average race car gets 2.0 miles per gallon and has a 22 gallon tank, it is limited to 44 miles between stops. If, however, a team found a way to make the engine run more efficiently and get 2.15 miles per gallon, then the same 22 gallon tank would be sufficient to drive 47.3 miles. That improvement allows them to go three and one-third laps farther between stops on a one-mile track than their competitors, a huge advantage in 400 mile race. The team that attains 2.0 miles per gallon will have to make 10 pit stops while the car achieving 47.3 miles on a tank of fuel only needs to make nine. One fewer pit stop will give them more than a lap lead in a race often won by a few feet.

Maximizing fuel efficiency is a tactic used very successfully by Ryan Newman, the NASCAR Nextel Cup driver of the number-12 car. In addition to driving professionally, Ryan is an engineer. His crew chief, Matt Borland, another engineer, understand work to energy very well.

How much work is done by the batteries in a radio controlled car?

It is easier to quantify the amount of work done by driving the R/C car up an inclined plane than by driving on a level surface.

The work done is equal to the weight of the car multiplied by the elevation change, or $E = m \times g \times h$; where E is the work done (work and energy have the same units), m is the mass of the car, g is the gravitational acceleration, and h is the elevation change from start to finish line.

Use the CBL unit with the TI-73 to measure the battery Voltage. In the case of the Ten80 Education kit, the 1/16th scale cars have 6 batteries and the voltage measured is the total for all 6 (in these cars the batteries are arranged in a series circuit, so the voltage of all the batteries is a sum of the 6).

Vocabulary:

Energy is the ability to do work.

Work is calculated by multiplying force by distance moved

Work =
force x distance

Power describes the rate of work

Power =
work ÷ time

useful unit conversions include,

1 N×m = 1 W×s =1 J

OR

1 Newton meter =
1 Watt second =
1 Joule

The Science of Racing
No Free Lunch

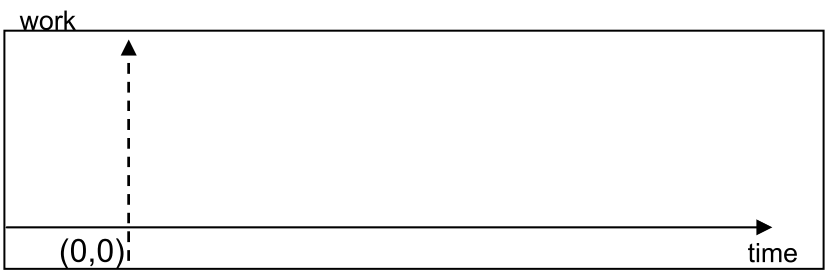
Student Investigation

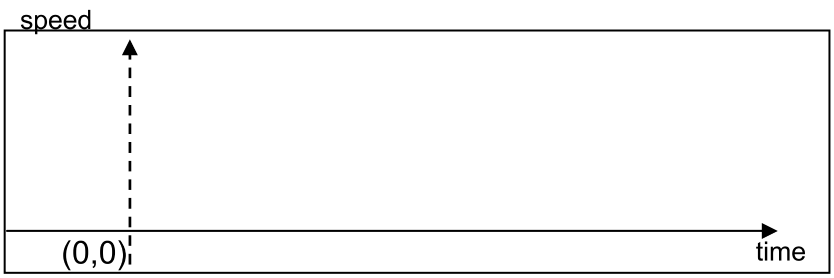
Name ______________Date______

1. **State the Objectives:**
   In this activity you will examine the relationship between work done by driving a radio controlled (RC) vehicle up an incline and the input energy source of six AA batteries.

2. **Identify the Focus Question or Problem:**
   Work output from any process comes at a price. That price is the energy input required to drive the process.
   - The purpose of data collection is to make a graph illustrating the total battery voltage as a function of the total work done.
   - How much work is really obtained from the batteries in a radio controlled race car?

3. **Make a prediction, Draw a Qualitative Graph:**
   Form a hypothesis about what you think will happen to the speed of the car and amount of work done by the car as it makes repeated runs up a hill (inclined plane). Draw a qualitative graph illustrating your hypothesis. C**heck your hypothesis by performing the investigation.**

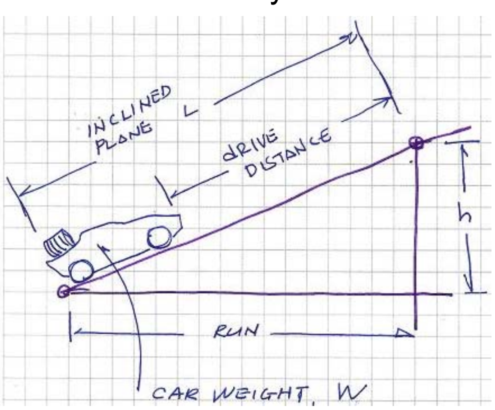




These activities are designed to be used with the TI 73 Explorer but are easily adapted to other TI calculators. Download more math2go lessons on the Science of Racing at www.ten80education.com

4. Plan an 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, a data recorder, calculator of the human kind and a crew chief who keeps track of all materials and schedules for completion of assignments.
- Set up an inclined plane. It can simply be an 8 ft x 2 ft board, a sidewalk, or a lane in a parking lot.
- Use a CBL and voltage probe to record the voltage at the beginning and end of a data set.
- Run the car several times up the ramp to simulate a long run on a single incline. The purpose of the run is to drain the battery power while calculating the amount of work done by the batteries as they drain.



- Record the time for several runs (5 – 20). These runs will constitute a data set.
- Multiply the number of runs by the track length, or distance (d), to get the total distance driven.
- Calculate the work done by the car by multiplying the height of the ramp by the weight of the car.
- Power can be calculated by dividing that work by time.
- Record as many data sets as possible.
- Calculate the total work done for the total voltage used.
- Define a relationship between work and energy and power and energy.
- **To learn to analyze the data, use Professor Pi's sample data. It can be accessed on the Transparency_No Free Lunch_5A**

Notes: Sample Track

Measure the length of the run as distance, d; (in the sample data, d = 84 inches.)

Measure the elevation change in the run distance; (in the sample data, h = 25 inches (0.635 m).)

The slope in this sample experiment is 17.30, or a rise to run of 0.312:1 (i.e., a 31.2% slope).

Carpenters would describe a set of steps for this incline as 1 in 3.2, a low angle for steps but a very steep incline for walking up hill or street.

Highways with a steep gradient, anything more than 5%, post warning signs for truckers to ensure their brakes are working properly. Railroads usually limit the tracks to less than 1% grade.

5. Begin the investigation, Collect and Analyze Data

- **Set up the ramp**
- **Weigh the car**
  - Weigh the car (total) as it is going to be driven on the track; (in the sample data, W was initially 30.7 ounces (8.54 N)) Maintain the same weight for a set of runs. You may need to change the weight if the car no longer climbs the ramp.
- **Attach CBL to the calculator**
- **Measure the voltage of the batteries in the car as soon as it is turned on but before it is driven.**
  - Section 10 has instructions for use of the CBL to collect and store data.
- **Collect a data set. Run the car up the ramp multiple times (5 – 20 times depending on the ramp length)**
  - Record the total run time, the total number of runs from which you will calculate distance and the ending voltage reading.
  - Record the start and ending voltage using the CBL probe and DATAMATE application each time you begin and complete a new set of runs.
- **Collect additional data sets to form a clear picture of how voltage decreases in comparison to work and power output.**
- **Calculate the work done after each set of runs and the total work done after all runs are completed. Calculate total Power that was expended.** Use Transparency_**No Free Lunch 5A** for sample data sets
  - Calculate the work that will be done on each trip; (lifting the RC car up the height of the incline); (in the sample data, 30.7 ounces x 25 inches = 767.5 inch*ounces, or 4.0 ft*lbs, or 5.423 N×m
  - Calculate the Power output by dividing Work by the time to make a set of runs. (In the sample data, Power is 33002 divided by 164.4.

Use Transparency_ **No Free Lunch 5A** for track set up

For technical questions
Phone 704-756-9348

For help with the experiment or to learn more about the Science of Racing, contact Professor Pi (a.k.a. engineer-scientist Jeffery Thompson) at ProfPi@ten80education.com

6. Collect Data

Group data into sets, where a set is defined by (1) an RC car of a given weight; (2) the same run distance; and (3) the same elevation change. This will allow you to calculate the work done (lifting the RC car up the height of the incline); and the time to make a set of runs. For each set, record:

- Starting voltage
- Number of runs up the incline that are done
- Total time to make those runs
- Ending voltage as soon as the set of runs is complete
- Car weight, W, a constant for a given set of runs
- Elevation change over the course of each run, h, a constant for a set of runs

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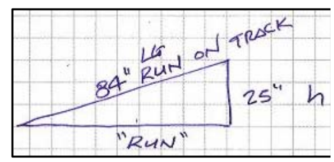

Weight = 30.7 ounces	**Length of ramp = 84 inches**	**Distance up = 25 inches**	**Work = 25 inches × 30.7 ounces × total runs**		X	Y
Time of runs in each data set	**Total # of Runs up the ramp in data set**	**Total time for data set (add as each set is completed)**	**Work (units are inch ounces)**	**Starting Voltage**	**Total Work (add as each set is completed)**	**Ending Voltage**

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Student Investigation

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A. Start the DATAMATE program

- Be sure that the TI-73 is connected to the CBL 2
- Press [PRGM] Select [1:DATAMATE].
- Press [ENTER] to start the program. The Main Screen appears.
- Select [1:SETUP].
- Select [MODE] by pressing [▼] Press [ENTER].
- Select [EVENTS WITH ENTRY]. [ENTER]
- Select 1:OK to return to the Main Screen.

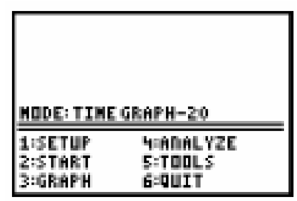
B. Attach the black and red leads to the battery

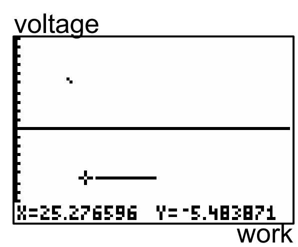
C. Collect data:

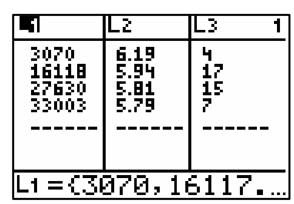
- Select [2:START].
- The screen displays **PRESS ENTER TO COLLECT OR STO TO STOP**.
- When the voltage reading is ready, press [ENTER].
- The program asks you to enter a value. This value will be the calculated WORK done during this set of data.
- If this is your first entry, type **1**) and press [ENTER]. Record the work beside the number in the table on the [Data Collection and Analysis] page. The program returns to the data collection screen, ready for your next voltage reading.
- Repeat step 3 for each sample, using the calculated work when the program asks for a value after you have the voltage. After you enter the first work value, the last number you used is displayed at the bottom of the screen.

D. Store and display data: Store Number of Runs and Work

- After you collect the last voltage reading run, press [STO▸]
- A scatter plot is displayed showing the voltage reading for all of the runs. Use [▸] keys to move to each data point and record the values in the table on the Data Collection and Analysis page.
- To exit from the DATAMATE program, press [ENTER] to return to the Main Screen.
- Select 6:QUIT and press [ENTER].
- Manually enter the number of runs for each data set in [LIST]L3, and enter the formula for total Work (L3 multiplied by weight by total distance in L4)

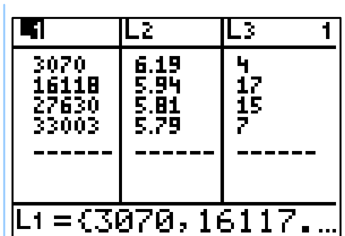


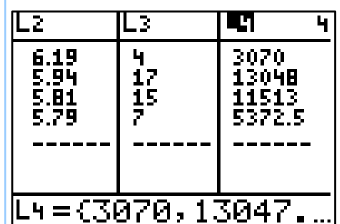


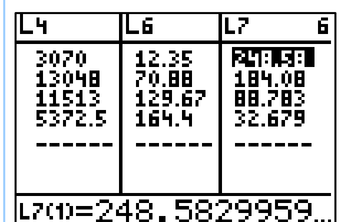


E. Analyze the data by graphing Voltage with respect to Work.

- The DATAMATE PROGRAM entered Work in L1 and Voltage in L2
- Create 4 more Lists from your data table.
  - Enter the number of runs up the ramp in each timed data set in L3. Use arrow keys to scroll up and over. Press [▼] after each entry.
  - Enter the formula for Work [distance x time] in L4 Highlight L4 [ENTER] [2nd][STAT] [▼] L2 [ENTER] x car weight x height of ramp.[ENTER]
  - These steps should result in the Total work for each data set being calculated in L4
  - Enter Total Times for runs in L5
  - Enter the formula for Power [work ÷ time] in L6 Highlight L6 [ENTER] [2nd][STAT] [▼] [▼] [▼] L4 [ENTER] ÷ [2nd][STAT] [▼] [▼] [▼] [▼] L5.[ENTER]

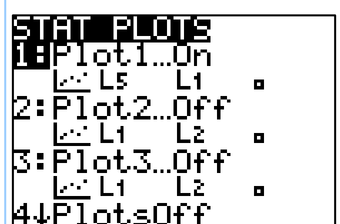


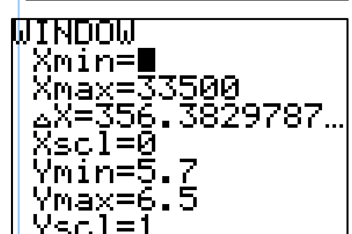




F. Define a Stats Plot

- for Voltage as a function of Work graph
  - [2nd][PLOT] [ENTER] Select ON for Plot 1
  - [▼] [▶] Select the plot [ENTER]
  - Select L1 for XList [2nd][STAT][ENTER][▼] and
  - L2 for YList [2nd][STAT] [▼] [ENTER].
  - Adjust Window value [WINDOW]
  - x min =0 x max=33500 Ymin=5.7 Ymax=6.5
  - [GRAPH][TRACE].
- for Voltage as a function of Power Output
  - [2nd][PLOT] [ENTER] Select ON for Plot 2
  - [▼] [▶] Select the plot [ENTER]
  - Select L1 for XList [2nd][STAT][ENTER][▼] and
  - L5 for YList [2nd][STAT] [▼] [ENTER].
  - Adjust Window value [WINDOW]
  - x min =0 x max=260 Ymin=0 Ymax=7
  - [GRAPH][TRACE].

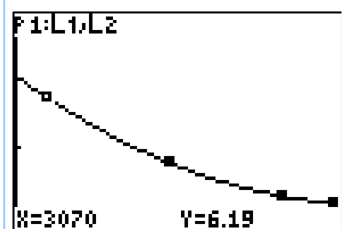




7. Your graph is a mathematical model.

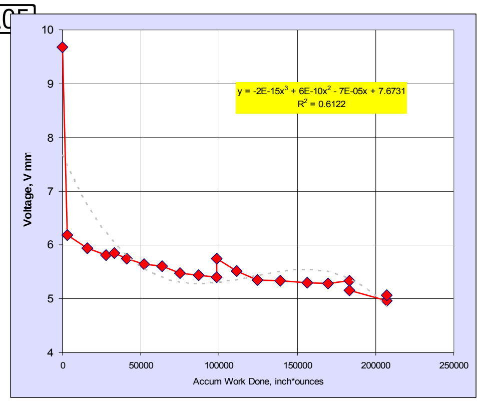
It is a model of what you observed just as the radio controlled car models a real car. Scientists and engineers work with mathematical models to make them as accurate as possible so that predictions made from them are as accurate as possible.

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]



Upon collecting even more data, the picture becomes clearer. There are several interesting points to note: overall, the voltage declines inexorably with continuing use; if the RC cars are turned off and allowed to "rest" for an hour or more the battery voltage 'recovers' slightly. (see the jump at 100,000 inch*ounces); and if the cars are left on but not actively used, the voltage decays because the radio part of the RC car system is using electricity as long as the car is turned on (note the drop in voltage in the area of 180,000 inch*ounces).

In the sample data it was necessary to reduce the weight of the car after the first five runs (the RC car would not climb the incline). With the reduced weight it was possible to make dozens of runs.

Voltage is the essential parameter that determines motor speed on these small direct-current (dc) electric motors.

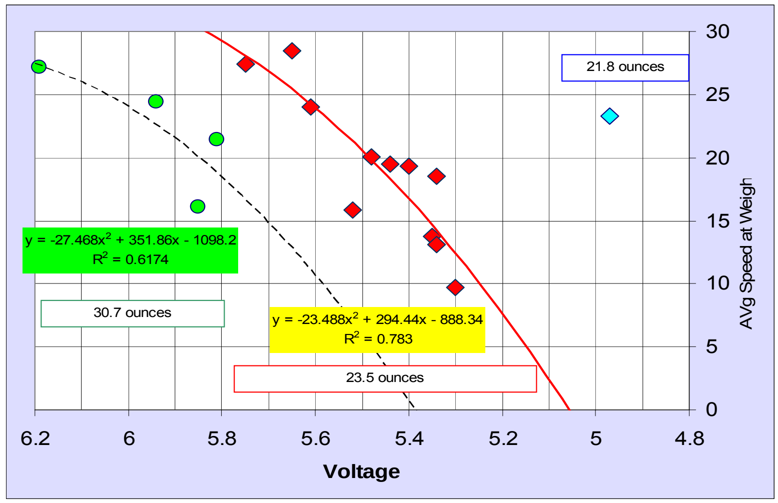
From a graph similar to the one above, you should be able to predict the decline in speed of an RC car as the voltage declines. From the data collected this can be quantified.

The Science of Racing

No Free Lunch

Summary Activity

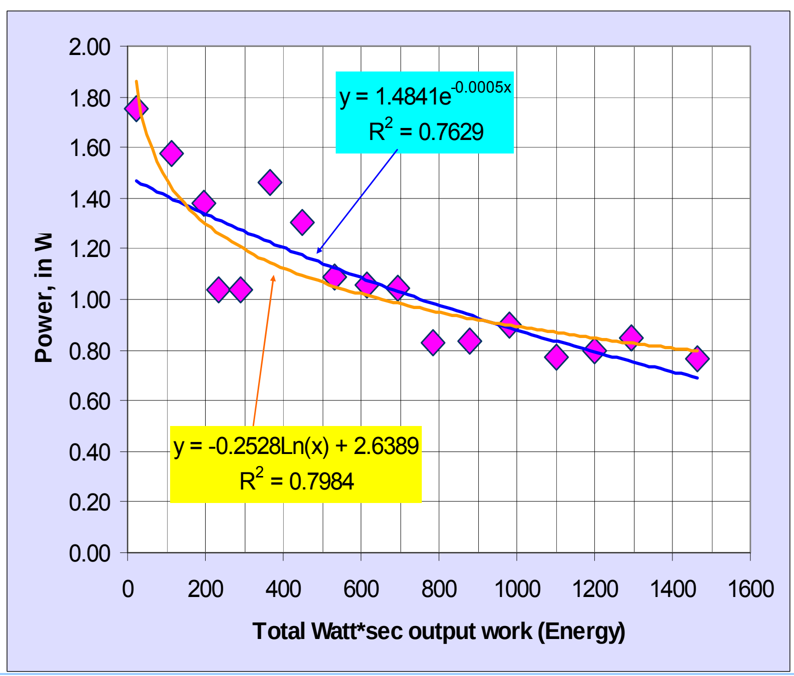
Notice in the sample data collected that there are three different sections of the data, in the first two sections the incline is the same, 25” rise on an 8’ long board; but the data is divided into regions for different weights.



At first an R/C car of 30.7 ounces was used, but then it was necessary to reduce the weight to 23.5 ounces (to allow the car to climb the hill). Finally it was necessary to reduce the weight again and reduce the slope of the hill (third region of data to the far right in the graph).

Power is Work done in a given period of time, i.e., (Work done) divided by (time period in which the work was done). As more work is done, the speed of the RC car declines.

You should then calculate the power delivered in driving the RC car up the incline as a function of the total work that has been performed. As more work is done, the speed of the RC car declines, (see above). You should then calculate the power delivered in driving the RC car up the incline as a function of the total work that has been performed.



Assessment:

- What is the difference in work and power?

- How would you describe the relationship between voltage and work for the car you tested? Quantify your answer.

- The car moves 30 ounces of added weight up the ramp at 70 inches per second for the first 10 runs of 120 inches each (total 100 feet). As the voltage dropped, the car moved the same weight at only 50 inches per second.

- Did the amount of work change in the second 10 runs?

- Did the amount of power change in the second 10 runs?

- Sketch a diagram that shows what happened to the voltage with respect to time during the investigation.

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No Free Lunch

Activity 3: No Free Lunch,
Additional Assessment:

Assessment:

- What is the difference in work and power?

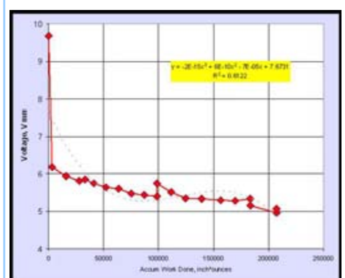
    •*Power is dependent on time. It is work done in some amount of time*.

- How would you describe the relationship between voltage and work for the car you tested? Quantify your answer.

    •*There are several interesting points to note: overall, the voltage declines inexorably with continuing use; if the RC cars are turned off and allowed to "rest" for an hour or two the battery voltage "recovers" slightly (see the jump at 100,000 inch*ounces); and if the cars are left on but not actively used, the voltage decays because the radio part of the RC car system is using electricity as long as the car is turned on (note the drop in voltage in the area of 180,000 inch*ounces).*

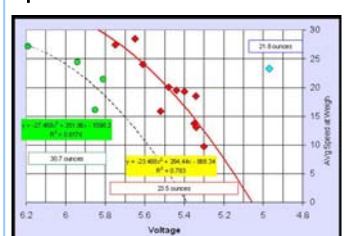
    •*In the sample data it was necessary to reduce the weight of the car after the first 5 runs (the RC car would not climb the incline). With the reduced weight it was possible to make numerous runs (dozens).*

voltage



work done

speed



voltage

- The car moves 30 ounces of added weight up the ramp at 70 inches per second for the first 10 runs of 120 inches each (total 100 feet). As the voltage dropped, the car moved the same weight at only 50 inches per second.

- Did the amount of work change in the second 10 runs?

    • *NO*

- Did the amount of power change in the second 10 runs?

    •*Yes*

- Sketch a diagram that shows what happened to the speed of the vehicle with respect to drop in voltage during the investigation.

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No Free Lunch

Transparency_No Free Lunch_5A

Use Professor Pi's data to learn to analyze the numbers and draw conclusions.

To learn more about the Science of Racing, contact Professor Pi at ProfPi@ten80education.com

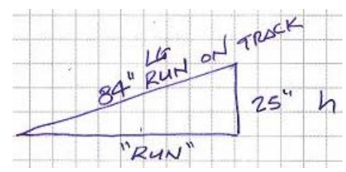
WEIGHT 23.5 oz h = 25"

DATE 31 Dec '05 13:08hr d = 84"

RUNS V = 5.35	TOTAL RUNS	WORK (in.oz)	TOTAL WORK	time	TOTAL time
	0	0	0	0	0
10	10	5875	5875	47.44	47.44
5	15	2397.5	8272.5	25.86	73.30
5	20	2397.5	10670	30.21	103.51
1	21	587.5	11257.5	5.83	109.34
12	33	7050	18307.5	68.33	177.67
V = 5.29					

Weight = 30.7 ounces

Distance up = 25 inches



					X	Y
Column a	**Column b**	**Column c= addition of times in column a**	**Column d= weight x distance**	**Column e**	**Column x= addition of work in column d**	**Column y**
Time of runs	**Total Runs in data set**	**Total time for data set**	**Work (units are inch ounces)**	**Starting Voltage**	**Total Work**	**Ending Voltage**
12.34	4	12.35	3070	9.68	3070	6.19
58.53	17			6.19		5.94
58.79	15			5.94		5.81
34.73	7			5.81		5.79

The Science of Racing
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Transparency_No Free Lunch_5B

Use Professor Pi's data to learn to analyze the numbers and draw conclusions.

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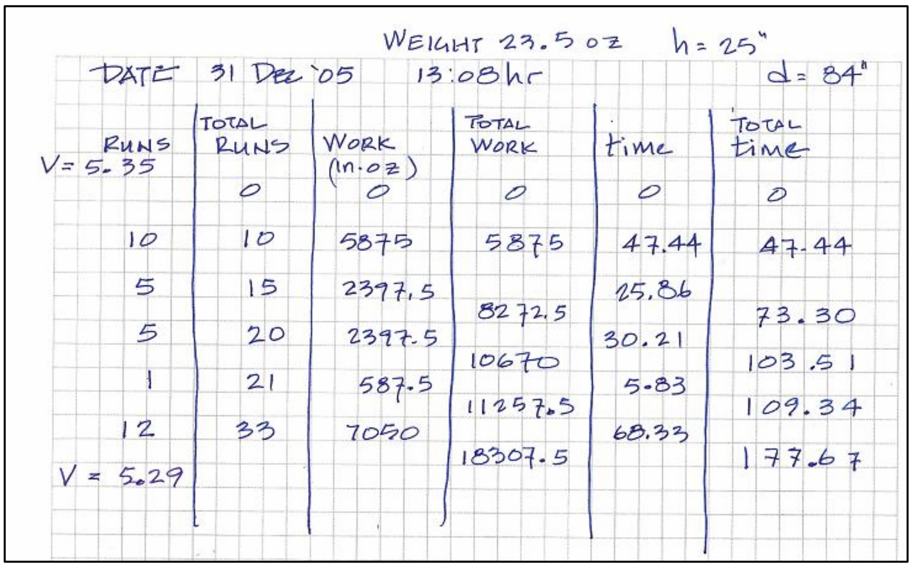
Professor Pi at math2go@bellsouth.net

Weight = 30.7 ounces

Distance up = 25 inches



WEIGHT 23.5 oz   h = 25"

DATE 31 Dec '05   13:08hr   d = 84"

V= 5.35

RUNS	TOTAL RUNS	WORK (in.oz)	TOTAL WORK	time	TOTAL time
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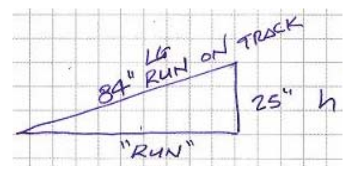
V = 5.29



					X	Y
Column a	**Column b**	**Column c= addition of times in column a**	**Column d= weight x distance**	**Column e**	**Column x= addition of work in column d**	**Column y**
Time of runs	**Total Runs in data set**	**Total time for data set**	**Work (units are inch ounces)**	**Starting Voltage**	**Total Work**	**Ending Voltage**
12.34	4	12.35	3070	9.68	3070	6.19
58.53	17	70.88	13047.5	6.19	16117.5	5.94
58.79	15	129.67	11512.5	5.94	27630	5.81
34.73	7	164.4	5372.5	5.81	33002.5	5.79

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
✓	✓	✓	✓	☑	☑
					☑
				☑	☑
					☑

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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